WORLD RESOURCES INSTITUTE

THE NEW CLIMATE ECONOMY

The Global Commission on the Economy and Climate

Working Paper

Summary for Policymakers

SEEING IS BELIEVING: CREATING A NEW CLIMATE ECONOMY IN THE UNITED STATES

NICHOLAS BIANCO, KRISTIN MEEK, REBECCA GASPER, MICHAEL OBEITER, SARAH FORBES, & NATE ADEN

A growing body of evidence shows that economic growth is not in conflict with efforts to reduce emissions of greenhouse gases. Experience at the state and national levels demonstrates that well-designed policies can reduce greenhouse gas emissions while providing overall net public benefits, for example, through improved public health, as well as direct financial benefits to businesses and consumers. Policies are often necessary to unlock these opportunities, however, because market barriers hamper investment in what are otherwise beneficial activities. Our analysis illustrates that many more opportunities could be realized with the right policy interventions, including the strengthening of existing policies and programs. In addition, we find that continued technological advancements could allow for even deeper reductions in the years ahead, as long as policies are put in place to help bring them to maturity.

OVERVIEW

This study examined several opportunities for reducing greenhouse gas emissions, including:

- Reducing the carbon intensity of power generation
- Improving electric efficiency in the residential and commercial sectors
- Building cleaner, more fuel-efficient passenger vehicles
- Improving production, processing, and transmission of natural gas, and
- Reducing consumption of high global warming-potential hydrofluorocarbons (HFCs)

These five measures can drive significant greenhouse gas emissions reductions. If done right, they can also lead to net economic benefits, even before the benefits of avoiding climate change are considered. The sectors considered

CONTENTS

Suggested Citation: Bianco, N. et al. 2014. "Summary for Policymakers, Seeing is Believing: Creating a New Climate Economy in the United States." Working Paper. Washington, DC: World Resources Institute. Available online at http://www.wri.org/publication/new-climate-economy.

here accounted for 55 percent of U.S. greenhouse gas emissions in 2012 and provide significant opportunity for emissions reductions.

For each measure, we examined recent developments and trends, identified current and emerging opportunities to reduce greenhouse gas emissions, highlighted some of the barriers to scaling these opportunities, and laid out strategies for driving a shift in investment. This working paper surveys peer-reviewed reports from academics, government laboratories, regulatory agencies, think tanks, industry associations, trade publications, and nongovernmental organizations, and complements that work with new analyses where warranted to help fill in the gaps.

This study is one of several in-country studies commissioned to support the research of the Global Commission on Energy and Climate, an international initiative to identify the economic benefits of acting on climate change. Its flagship project is the New Climate Economy, which identifies the opportunities for enhanced economic performance and climate action in urban, land use, and energy systems across a range of country circumstances.

DELAYING ACTION WILL HAVE SIGNIFICANT ECONOMIC IMPACTS

Climate change itself constitutes a significant risk to the nation's economy. We are beginning to see some of these impacts today. Globally, 12 of the 13 warmest years on record occurred within the last 15 years.[1] Some extreme weather and climate events, such as heat waves and wildfires in the West and heavy downpours in the Midwest and Northeast, are becoming more frequent and intense.[2] These changes will continue unless significant action is taken to reduce greenhouse gas emissions. For example, the conditions that led to the 2011 Texas heat wave, which cost $5 billion in livestock and crop losses, are 20 times more likely to occur today than in the 1960s.[3] Over the longer term, unless action is taken to reduce greenhouse gas emissions, climate-related damages are expected to mount considerably, resulting in up to a 20 percent reduction in per capita consumption globally.[4]

Delaying action will result in real costs from greater warming and increase the number of stranded high-carbon investments. A July 2014 report by President Obama's Council of Economic Advisers concluded that each decade of delay will increase the costs of mitigation by 40 percent on average, with higher costs for more ambitious climate goals. The council further found that with each year of delay "it becomes increasingly difficult, or even infeasible, to hit a climate target that is likely to yield only moderate temperature increases."[5]

WE DON'T HAVE TO CHOOSE BETWEEN ECONOMIC GROWTH AND AVERTING CLIMATE CHANGE

A September 2014 study by the Global Commission on Energy and Climate found that key drivers of further economic growth—namely greater resource and energy efficiency; investment in infrastructure; and enhanced innovation—can also be key drivers of greenhouse gas emissions reductions, if they are done right. This finding is supported by a growing body of literature that concludes that supporting economic growth and tackling climate change are not mutually exclusive, and indeed that in certain circumstances, well-designed climate change policies can actually boost economic growth. The ability to reduce greenhouse gas emissions while benefitting the economy has already been demonstrated through numerous policies and programs implemented in the United States. For example:

- **Capping emissions in the Northeast is reducing electric bills and creating jobs.** Energy efficiency and other investments made during the first three years of the Regional Greenhouse Gas Initiative, a regional cap-and-trade program for carbon dioxide emissions from power plants in nine Northeast and mid-Atlantic states, will save customers nearly $1.1 billion on electricity bills and create 16,000 net job-years while adding $1.6 billion in net present economic value to the region's economy, according to a study by the Analysis Group.[6]

- **Energy efficiency programs provide multiple benefits.** State energy efficiency programs regularly save consumers $2 for every $1 invested, and in some cases up to $5. But the benefits extend beyond direct financial savings to consumers. For example, according to the Wisconsin Public Service Commission, the state's energy efficiency program is expected to inject over $900 million into the state's economy and net over 6,000 new jobs over the next 10 years. After taking into account the benefits from reduced electricity and natural gas bills as well as avoided air pollution, total benefits are estimated to be three times greater than program costs.[7] Similar results are seen across the 24 states that have energy efficiency savings targets (see Chapter 2 of the full Working Paper).

- **Improved cars and light trucks reduce pollution and save drivers money.** New standards for cars and light trucks will cause them to emit roughly one half as much carbon pollution in 2025 as vehicles sold in the United States today. The Department of Transportation and the Environmental Protection Agency (EPA) estimate that model year 2025 car and light truck owners will save a net $3,400 to $5,000 on average over the life of their vehicle (compared with a vehicle meeting model year 2016 standards) as a result of lower fuel costs. They further estimate that the standards will produce net savings of $186 to $291 per metric ton of CO_2 reduced for model years 2017–25 in 2030 and 2050, respectively. These standards will also help reduce America's dependence on oil by more than 2 million barrels per day in 2025 (which could help reduce U.S. oil imports) and result in $3.1 to $9.2 billion in benefits (net present value) from reducing non-greenhouse gas air pollutants.[8] Plus, the model year 2017–25 light-duty vehicle standards could result in a net gain of 570,000 jobs and an increase of $75 billion in annual gross domestic product by 2030, according to American Council for an Energy-Efficient Economy estimates.[9]

- **Reducing waste from natural gas systems can improve air quality and save money for industry.** EPA's 2012 standards for natural gas systems aimed at reducing emissions of hazardous air pollutants, sulfur dioxide (SO_2), and volatile organic compounds are also expected to significantly reduce methane emissions while saving the gas industry $10 million per year in 2015. This is because the value of the avoided emissions of natural gas is greater than the cost of controls, according to EPA analysis (annual savings are estimated at $330 million versus $320 million in compliance costs). When including the value of reduced air pollution, the net benefits increase considerably. EPA estimates that the standards will reduce emissions of volatile organic compounds by 172,000 metric tons in 2015 alone.[10] Some studies have suggested that the public health impacts from these emissions could be as high as $2,640 per metric ton nationwide, and even higher in some localities.

- **Industry has a history of developing cost-effective alternatives for refrigerants.** The global phase out of chlorofluorocarbons (CFCs) under the Montreal Protocol, which aims to protect the ozone layer, will result in an estimated $1.8 trillion in global health benefits and almost $460 billion dollars in avoided damages to agriculture, fisheries, and materials that would have been caused by depletion of the ozone layer (both cumulative estimates from 1987 to 2060). The CFC phase-out has also reduced greenhouse gas emissions by a net 135 billion metric tons of CO_2 equivalent between 1990 and 2010 (about 11 billion metric tons CO_2 equivalent per year annually). Consumers around the world were not faced with higher prices for new products, and some of the new products were cheaper to maintain than the replaced equipment because of higher efficiencies, product quality, and reliability.[11]

As shown in the sections that follow, these five examples are hardly unusual, and, in fact, are representative of a much broader trend of smart policies and actions that reduce greenhouse gas emissions while also delivering benefits to the broader economy.

SUSTAINED TECHNOLOGICAL PROGRESS CREATES NEW OPPORTUNITIES

In each of the five areas we examined, sustained technological progress continues to create opportunities to reduce greenhouse gas emissions while delivering net economic benefits. We profile a number of low-carbon options that are already cost competitive with, and in some cases cheaper than, their high-carbon alternatives. Continued maturation of these technologies could increase the number of markets where they can compete. Plus, a number of new technologies on the horizon could unlock much deeper reductions of greenhouse gas emissions. For example:

- **Natural gas and renewable generation is cheaper than coal in many markets.** New natural gas-fired power plants now cost 19-44 percent less than new coal-fired power plants.[12] Meanwhile, wind and solar are cost competitive in a growing number of markets. Recent price declines for solar photovoltaics are particularly pronounced, with module costs falling 80 percent since 2008.[13] Increased renewable energy generation has the potential to save American ratepayers tens of billions of dollars a year over the current mix of electric power options, according to studies by Synapse Energy Economics and the National Renewable Energy Laboratory.[14] Continued technological progress could increase the number of markets in which renewable generation can compete with existing fossil-based electric generation.

- **Product efficiency continues to improve, creating new opportunities for customers to save money.** A number of major appliances are 50–80 percent more efficient than they were just a few decades ago. Nevertheless, in many states, utilities can procure energy efficiency at one-half to one-third the cost of new electricity generation. Technological advancement continues to create new opportunities for consumers to save money. For example, prices for light-emitting diodes (LEDs) have fallen 80 percent since 2012.[15] These bulbs use one-seventh the amount of electricity as an incandescent bulb, saving consumers up to $140 for every bulb they replace.[16] Intelligent building energy management systems have the ability to reduce building electricity use by as much as 30 percent, and are beginning to take hold in the marketplace. If successful, wide bandgap semiconductors—used in power conversion in consumer electronics—could eliminate up to 90 percent of the power losses that occur in electricity conversion from AC to DC.[17]

- **Vehicles are getting more efficient, and new technologies could transform the light-duty vehicle sector.** Since the implementation of new CO_2 emissions and fuel economy standards for cars and light-duty trucks, the number of vehicles with a fuel economy of 40 miles per gallon or more has increased sevenfold. A growing number of vehicles use energy-saving technologies such as variable valve timing, gasoline direct injection, turbochargers, hybrid engines, and six- and seven-speed transmissions. Meanwhile, next-generation vehicles are moving ahead. Battery prices for electric vehicles have fallen by 40 percent since 2010. This trend is likely to continue; Tesla Motor Company plans to build facilities by 2017 to produce batteries that are 30 percent cheaper than today's batteries. Some industry analysts predict that long-range electric vehicles will become cost competitive with internal-combustion-engine vehicles by the early 2020s, even without federal tax incentives. Meanwhile, several large automakers continue to pursue fuel cells for light-duty vehicles, with commercialization expected in 2015–17.

- **Cost-saving measures can reduce waste from natural gas systems.** Methane emissions from natural gas systems can be reduced using technologies available today, such as dry-seal centrifugal compressors, low-bleed pneumatic devices, and infrared-camera-assisted leak detection and repair. By reducing the amount of product lost through leaks and venting, these measures can save the industry money. Emissions can be reduced by 25 percent or more through measures that pay for themselves in three years or less, and even deeper reductions are possible at just a few cents per thousand cubic feet of gas. However, opportunity costs and principal-agent problems present barriers to achieving the full potential of emissions reductions.

- **New alternatives for high global warming-potential hydrofluorocarbons (HFCs) are entering the marketplace.** The United States can reduce HFC emissions by over 40 percent from what would otherwise be emitted in 2030 entirely through measures possible at a negative or break-even price today, according to data from EPA.[18] Companies around the world—including General Motors, Coca-Cola, Red Bull, and Heineken, among others—are already beginning to employ some of these technologies. Some of these companies began doing so for environmental reasons, but as technologies have matured, many more are discovering the economic benefits of the alternatives. Convenience stores in Japan have reported 10 to 26 percent energy savings from using HFC alternatives, while some supermarkets have achieved 19 to 21 percent energy savings.[19] Meanwhile, even more technologies now in the pipeline are expected to be available within the next five years, and could allow for even deeper reductions in greenhouse gas emissions.[20]

POLICIES CAN OVERCOME MARKET BARRIERS AND FACILITATE INVESTMENT AND INNOVATION

While existing cost-saving opportunities are being pursued, in many instances market and other barriers get in the way and prevent widespread adoption. Some of the common barriers hampering the shift to low-carbon growth include: split incentives, ownership transfer issues, network effects, imperfect information, capital constraints, and externalities. For example:

- **Split incentives** can impede investments in cost-saving measures in the natural gas sector. This is because thousands of companies are active in the U.S. natural gas industry, from contractors that drill wells to pipeline operators to the local utilities that operate the million-plus miles of small distribution pipelines. With so many independent actors, the incentives for investment in emissions control technologies are not always well aligned because the companies that are able to reduce methane emissions are not always the same companies that reap the benefits of those investments.

- **Ownership transfer issues** can impede investment in energy efficiency, for example, when an investor does not expect to capture the full lifetime benefits of an investment. This is a significant barrier in residential buildings where energy efficiency measures have an average payback period of seven years, yet 40 percent of homeowners will have moved in that time.

- Widespread penetration of electric cars depends on the development of a robust network of charging stations. However, it is less profitable to build new charging stations when there are only a few drivers of electric vehicles. Therefore, policy intervention is required in the early stages to reap the longer-term societal benefits of the network. (This chicken-and-egg situation is commonly referred to as **network effects**.)

- In a number of sectors, including electricity generation, the persistence of pollution **externalities** gives an unfair advantage to polluting activities. Externalities occur when a product or activity affects people in ways that are not fully captured in its price, such as the full health effects of air pollution not being factored into the cost of electricity generation. Thus society, rather than the company, pays the cost.

Well-designed policies can overcome these market barriers and direct investment into beneficial technologies and practices. Likewise, they can influence the rate at which emerging technologies mature by driving research, development, and deployment, thus ensuring advancement through learning-by-doing, and helping overcome network effects, among other factors. In this working paper, we identify a number of policies that can help promote both existing and emerging technologies. By so doing, new policies can enhance the transition to a low-carbon economy while delivering net economic benefits and, in many cases, direct savings for consumers and businesses.

This working paper identifies a number of opportunities to reduce greenhouse gas emissions while fostering economic growth. However, we are not suggesting that the United States should limit its climate policies to just these win-win opportunities. Climate change itself imposes economic costs, and reducing each ton of greenhouse gas emissions has a value that is not currently internalized in the U.S. economy. Indeed, analysis by the Interagency Working Group on the Social Cost of Carbon for the United States found that the damage of each incremental ton of CO_2 emitted in 2020 is between $13 and $144 (in 2013 dollars).[21] Fully incorporating the value of the benefits of reduced greenhouse gas emissions into economic decisions and policymaking will ultimately lead to better outcomes for both the U.S. economy and environment. Nevertheless, as we show here, numerous actions can be taken today that will produce net positive economic benefits even before accounting for the avoided impacts of climate change.

PRELIMINARY RECOMMENDATIONS

1. Produce Cleaner Electricity

- To make good long-term decisions that minimize stranded assets and maximize return on investment, the industry needs **long-term regulatory certainty.** EPA has taken a step in this direction by proposing carbon pollution standards under section 111(d) of the Clean Air Act. Regulatory certainty could also be provided through legislative measures such as a clean energy standard, a greenhouse gas tax, or a greenhouse gas cap-and-trade program.

- The transition to a low-carbon future will be cheaper and easier with the right policy support. Specifically, we find that:

  - States and utilities should **enhance access to long-term contracts** by renewable energy providers, which could reduce the average electricity costs over the lifetime of typical wind and solar projects by 10–15 percent.[22]

  - Congress should **stabilize federal tax credits and eliminate inefficiency in their design** so that more of the value of the credit flows to project developers without increasing the cost to taxpayers.[23]

  - Financial regulators and lending institutions should work together to develop commercial investment vehicles that align the risk profile of low-carbon assets with the needs of investors to **reduce the costs of finance.**

  - States and utilities should update regulations and business models to **promote a flexible power grid**, allowing customers and utilities to maximize their use of low-cost variable generation such as wind and solar.

- EPA should **finalize greenhouse gas performance standards** for new and existing power plants. Together, these standards will: (1) help with the nation's efforts to reduce greenhouse gas emissions; (2) deliver public health benefits through improved air quality; (3) reduce the risk of technological lock-in and stranded assets; and (4) encourage investment in natural gas generation and renewables.

- The United States should **increase federal funding for research, development, and commercialization** of low-carbon and energy-saving technologies. This would help foster opportunities for American businesses and manufacturing by helping the country remain a world leader of innovation.

2. Reduce Electricity Consumption

- The United States should **scale up its existing initiatives**, which are already delivering benefits many times their costs. This includes, but is not limited to:
  - Strengthening and expanding federal appliance and equipment standards;
  - Enhancing efforts to deploy new technology (e.g., research and development, partnerships with industry, competitions, voluntary labeling, rebates and incentives for efficient appliances);
  - Strengthening existing state energy efficiency targets, and adopting targets in states without them;
  - Pursuing policies to better align utility incentive structures, such as: providing performance incentives for energy efficiency, requiring utilities to consider efficiency as part of their integrated resource planning, and decoupling, among other policies.

- New federal policies should be implemented to **promote the proliferation of ambitious state efficiency policies**, thus expanding the number of consumers that benefit from increased energy efficiency. This could include new **legislation**, such as a nationwide electric energy-efficiency resource standard, a clean-energy standard, and a greenhouse gas cap-and-trade program or carbon tax, including the option to recycle revenue into energy-efficiency measures. **EPA's proposed carbon pollution standards for existing power plants** could also be an important addition to the toolkit, since they allow states to make progress toward their carbon dioxide emissions reduction targets through efficiency programs.

- Federal, state, and local governments should ensure that consumers benefit from the latest cost-saving building technologies by **encouraging adoption and enforcement of the most up-to-date building codes**.

- Federal, state, and local governments should help unlock cost-saving opportunities available through **retrofits to existing buildings** by (1) expanding labeling and energy assessment tools; (2) implementing building energy auditing, disclosure, and benchmarking policies; (3) recognizing the benefits of energy efficiency in mortgages; and (4) incentivizing whole-building retrofits.

- Federal, state, and local governments should take steps to **improve access to low-cost financing** options to help address barriers that might otherwise be created by high up-front costs. Specifically, they should: (1) stimulate private funding; (2) improve access to property assessed clean energy (PACE) financing; and (3) pursue other innovative financing options (e.g., by establishing "green banks").

3. Develop and Deploy Cleaner and More Efficient Passenger Vehicles

- Corporate Average Fuel Economy (CAFE) standards and greenhouse gas emissions standards are poised to deliver significant benefits to consumers as a result of lower ownership costs and improved air quality. Depending on the progress of technology over the coming years, these **standards may warrant strengthening**.

- In the meantime, complementary policies by federal, state, and local governments can help promising technologies realize their potential:
  - **Increase the number of alternative fuel stations** (e.g., electricity and hydrogen) to help ease drivers' range anxiety and provide the certainty auto companies need to commit to manufacturing alternative-fuel vehicles.
  - Charging options should be improved by **eliminating barriers to access and adopting communication standards** for controlled charging by grid

operators. This would allow electric vehicle charging to better align with periods of high generation from variable renewable resources and provide low-cost grid stabilization as well as reduce charging costs for electric vehicle owners.

- **Research and development** for next-generation technologies should be expanded to help the United States take a leadership position in alternative vehicle manufacturing.

- Federal and state **mandates and incentives to promote sales of alternative vehicles** should be sustained and expanded to help accelerate the technology learning curve and bring lower-cost alternative vehicles to market faster.

4. Improve the Production, Processing, and Transmission of Natural Gas

- **Emissions standards for natural gas systems** should be implemented or strengthened to help correct the market failures that leave many cost-saving opportunities on the table. These standards could be achieved through section 111 of the Clean Air Act, through Congressional legislation, or through standards implemented at the state level.

- Agencies like the Federal Energy Regulatory Commission and EPA should work with industry to **revise contracts in such a way that service providers throughout the natural gas supply chain share in the benefits of reducing waste** and increasing the amount of natural gas brought to market.

- The Department of Energy (DOE) should work to improve emissions measurement and control technologies through **continued research and development**. Reducing the cost of this equipment will further encourage voluntary measures to reduce emissions, and lower the cost of complying with future standards from EPA.

- The Pipeline and Hazardous Materials Safety Administration could require **stricter inspection and maintenance standards** for gathering, transmission, and distribution systems, which would improve safety and increase industry revenues while reducing methane emissions from those sectors.

5. Reduce Emissions of Hydrofluorocarbons (HFCs)

- The United States should continue to work to achieve an international phase-down of the consumption of high-global-warming-potential (GWP) hydrofluorocarbons (HFC) through **amendments to the Montreal Protocol**.

- In the meantime, EPA and Congress can take the following steps to reduce domestic emissions of high-GWP HFCs:

  - EPA should use its authority under its Significant New Alternatives Policy program (SNAP) through section 612 of the Clean Air Act. This includes **finalizing proposed regulations to delist some uses of high-GWP HFCs** and continuing to phase down HFCs where safer, cost-effective alternatives exist. This will help harness win-win opportunities. EPA previously estimated that HFC emissions could be reduced by over 40 percent from what would otherwise be emitted in 2030 entirely through measures that come at a negative or break-even price today.

  - EPA should work toward **ensuring that the alternatives development process moves swiftly** and that new chemicals are quickly, yet thoroughly, tested for their safety and performance. EPA should also **finalize its proposed regulation to list new alternatives** and continue evaluating and approving appropriate low-GWP alternatives.

  - EPA should **extend the servicing and disposal of air conditioning and refrigeration equipment requirements** for HCFCs and CFCs to HFCs (under section 608 of the Clean Air Act) as well as increase initiatives for HFC reclamation and recycling to ensure that fewer virgin HFC compounds are used until they are phased down.[24]

  - Over time, it may also be appropriate to implement a **flexible program** to reduce emissions of high-GWP HFCs either by EPA under section 615 of the Clean Air Act or via Congressional legislation, as the flexibility provided by these programs could allow for deeper reductions in a cost-effective manner.

Box ES.1 | Nationwide Emissions Have Fallen, But More Work Remains

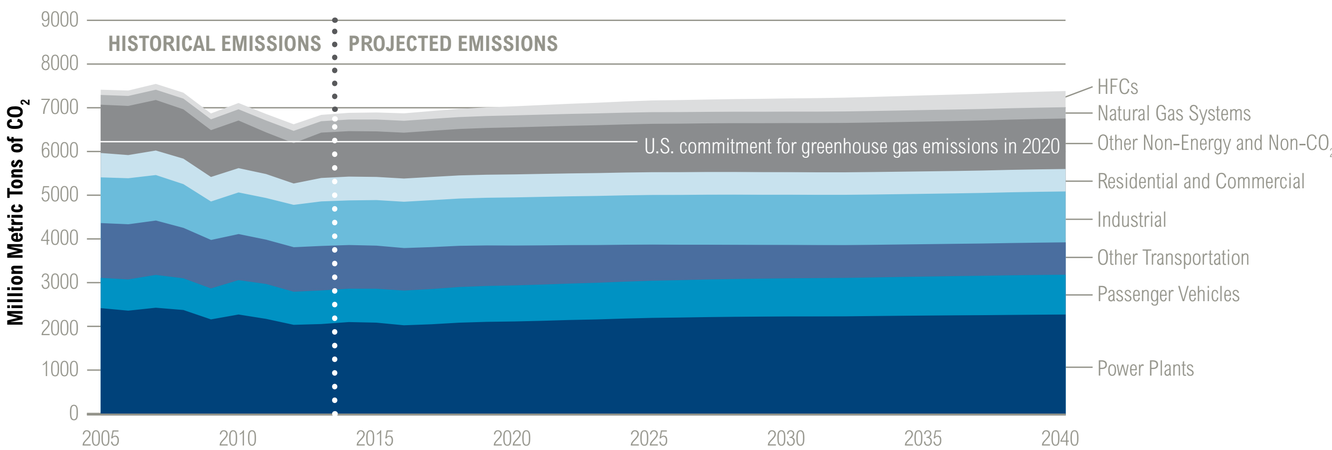
The United States has already begun to decouple its emissions from economic growth. From 2005 to 2013, energy-related CO_2 emissions fell 10 percent in absolute terms (Figure ES.1),[a] while real gross domestic product increased 11 percent.[b] These CO_2 reductions were the result of reduced residential electricity demand, a reduction in the carbon intensity of power generation, and reduced transportation emissions, among other factors.[c]

A number of state and federal policies contributed to these trends, and these policies have multiplied in recent years. However, as we conclude in the World Resources Institute report, "Can the U.S. Get There From Here?" the country is not expected to meet its international commitment to reducing emissions 17 percent below 2005 levels by 2020 unless significant new policies are adopted.[d]

The policies proposed by the Administration in 2013 and 2014 will help, but more will be necessary to reach the 2020 target and then to achieve the even more rapid emissions reductions needed thereafter to keep global temperature rise below 2°C. The current portfolio of standards and current market forces are not sufficient to drive a continued decline in CO_2 emissions from fossil fuel combustion, and other greenhouse gas emissions (both non-energy and non-CO_2 emissions) are expected to rise 15 percent above 2005 levels by 2020, largely because of increasing emissions of hydrofluorocarbons.[e,f,g]

However, that trajectory could shift considerably if the Administration adopts proposed policies, including greenhouse gas performance standards for existing power plants and new rules to reduce HFC emissions. The question is: Will these actions and others being considered go far enough to reach the 17 percent reduction target and achieve deep reductions in the years that follow?

Figure ES.1 | U.S. Actual and Projected Greenhouse Gas Emissions by Sector, 2005–40



Note: Projections only include policies finalized as of August 2014, and do not include recently proposed standards for existing power plants or HFCs.

Sources for energy emissions: U.S. Energy Information Administration, Annual Energy Review (Years 2005–13) and Annual Energy Outlook (Years 2014–40).
Sources for non-energy and non-CO_2 emissions: U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012" (Years 2005–12); U.S. Department of State, "U.S. Climate Action Report 2014" (Years 2013–14); World Resources Institute, 2013, "Clearing the Air: Reducing Upstream Greenhouse Gas Emissions from U.S. Natural Gas Systems."

Notes:

a. U.S. Energy Information Administration, "Table 12.1 Carbon Dioxide Emissions From Energy Consumption by Source," accessible at http://www.eia.gov/totalenergy/data/monthly/pdf/sec12_3.pdf.

b. U.S. Department of Commerce, Bureau of Economic Analysis, "Real Gross Domestic Product," Chained Dollars, accessed September 02, 2014, accessible at http://www.bea.gov/iTable/iTable.cfm?ReqID=9&step=1#reqid=9&step=3&isuri=1&910=x&911=0&903=6&904=2000&905=2013&906=a.

c. U.S. Energy Information Administration, "U.S. Energy-Related Carbon Dioxide Emissions," October 2013, accessible at: http://www.eia.gov/environment/emissions/carbon/.

d. N. Bianco, F. Litz, K. Meek, and R. Gasper, 2013, "Can the U.S. Get There from Here?" World Resources Institute, February, accessible at http://www.wri.org/publication/can-us-get-there-here.

e. Ibid.

f. As highlighted in this study, there are also emerging opportunities for cost-effective reductions in HFCs.

g. WRI estimates based on data from the following sources: U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012," and U.S. Department of State, "U.S. Climate Action Report 2014," (non-energy CO_2 and non-CO_2 emissions); U.S. Energy Information Administration, "Annual Energy Review," and U.S. Energy Information Administration, Annual Energy Outlook 2014 (most energy CO_2 emissions); World Resources Institute, 2013, "Clearing the Air: Reducing Upstream Greenhouse Gas Emissions from U.S. Natural Gas Systems," (methane emissions from natural gas systems).

PRODUCING CLEANER ELECTRICITY

Overview

The U.S. power grid has already begun to decarbonize.[25] In 2013, carbon dioxide (CO_2) emissions were 15 percent below 2005 levels because of a reduction in the carbon intensity of electric generation and slowed demand growth.[26] Coal's role appears to be diminishing, while natural gas and zero-carbon alternatives are on the rise. The economics of all generation sources are shifting. If these trends continue, it may be possible to achieve deep greenhouse gas reductions from the power sector at a much lower cost than is commonly assumed, with net savings in some parts of the country. When layering in the public health benefits that can result by replacing old, inefficient, and heavily polluting generation with new, cleaner generation (which also happens to be low-carbon), this transition could bring significant net benefits to the American public.

Summary of Findings

The recent decarbonization of the power sector has been assisted by low prices for natural gas.[27] Lower prices have caused a surge in gas-fired generation and a corresponding decline in generation from coal, the dominant fuel for electricity, which accounted for only 5 percent of the new capacity built since 2000. The question is how much further the shift from coal to natural gas will go. Favorable natural gas prices and more protective public health standards could lead to a wave of coal plant retirements in the coming years. Fewer coal plants could lead to an increase in generation at existing combined-cycle natural gas plants, which only ran at about 51 percent capacity in 2012[28]—well below their design capacity of 85 percent. It could also lead to an increase in construction of new gas plants, which cost about 19–44 percent less than new coal plants. More natural gas and less coal generation would bring not just reductions in CO_2 emissions, but would also likely bring reductions in a variety of pollutants, including sulfur dioxide (SO_2), nitrogen oxides (NO_x), and mercury.

Despite its reputation as a clean fuel, natural gas combustion still results in CO_2 emissions, presenting long-term challenges for the fuel unless it employs carbon capture and storage technology. However, it still can play an important role in the decarbonization of the power sector. Replacing all existing coal generation with combined-cycle gas generation could reduce power-sector CO_2 emissions by 44 percent below 2012 levels. Importantly, as variable generation from resources such as wind and solar increases, grid operators will look to flexible resources like natural gas to help ensure grid reliability, suggesting that gas could play an important role even in an aggressive greenhouse gas abatement scenario.[a]

Renewable generation has been on the rise in recent years, and evidence suggests that it could play an even more significant role in the future. Generation from renewable resources accounted for 12.5 percent of total generation in 2013—nearly half of which came from non-hydropower sources.[29] Wind and solar outcompete coal in many markets, and are competitive with low-cost natural gas in a few markets (see Figure ES.2). As a result, increased renewable energy generation has the potential to save American ratepayers tens of billions of dollars a year over the current mix of electric power options, according to studies by Synapse Energy Economics and the National Renewable Energy Laboratory.[30] These cost savings are borne out by recent actions at the state level. For example:

- In a recent survey of renewable and fossil contracts submitted to the Michigan Public Service Commission, the state found that the most recent utility-scale wind power contracts were about half the price of new coal generation.[31]
- Austin Energy in Texas finalized a power purchase agreement that will bring them 150 megawatts of solar energy at a price of just under 5 cents per kilowatt hour (estimated at 7 cents per kilowatt hour without federal tax credits).[32] By comparison, the company estimates that new natural-gas-fired generation would cost 7 cents per kilowatt hour, coal 10 cents, and nuclear 13 cents.
- MidAmerican generation in Iowa announced that they will invest $1.9 billion in new wind power, bringing wind generation up to 39 percent of their generation portfolio.[33] The company estimates that this will cause rates to go down by $10 million annually when all the turbines are completed, while creating 460 construction jobs, 48 permanent jobs, and generating more than $360 million in new property tax revenue.

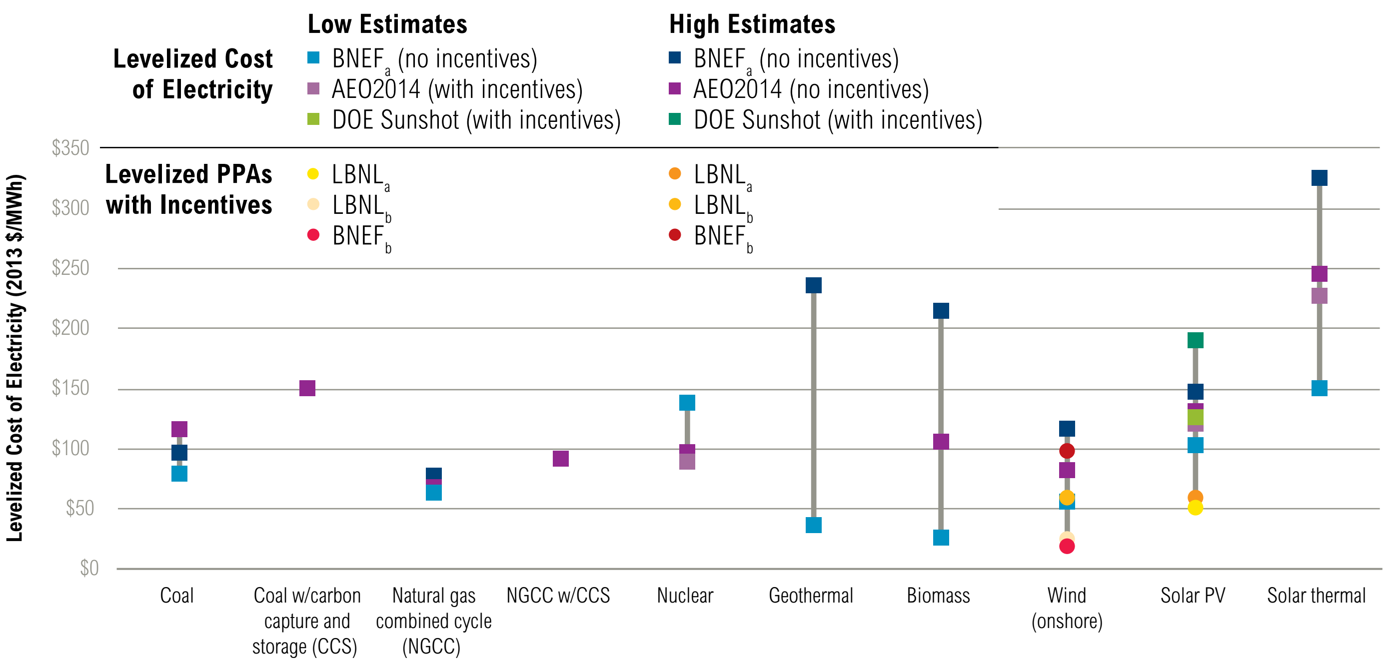
While the variability of renewable generation creates some challenges for grid balancing authorities, renewables have considerable room to expand on the grid. Several studies have shown that existing grids across the country can

a. Natural gas plants can cycle up or down more quickly, and more cheaply, than coal or nuclear plants, making them a more natural fit to serve as back-up generation for variable renewable resources.

handle about 35 percent generation from variable renewable resources with minimal cost.[34] This is partly because of improvements in renewable energy forecasting and sub-hourly supply scheduling, as well as recent increases in transmission infrastructure.[35, 36] Over the longer term, however, as renewable penetration continues to increase with expected declines in equipment costs, the United States would benefit from expanded transmission[37] and increased system flexibility, for example through increased grid storage, distributed generation sources, and demand response.[38]

Nuclear power provides around-the-clock baseload generation that is free of CO_2 emissions. In 2013, it was responsible for 20 percent of total U.S. electric generation and over 60 percent of total U.S. carbon-free electric generation.[39] As of mid-2014, three new nuclear plants were under construction, the first new plants since 1996.[40] However, several nuclear reactors closed in 2013[41] and some analysis suggests that some other plants are struggling to remain viable as a result of cheap natural gas, low renewable energy prices, lower demand for electricity, and rising costs for nuclear fuel, operations, and maintenance (particularly the smaller, older, standalone units).[42]

Figure ES.2 | **Levelized Cost of Electricity ($/MWh) for New Generation Sources and Levelized Power Purchase Agreement Prices for Recent Wind and Solar Projects**



Note: This figure depicts the estimated cost for new power plants (levelized cost of electricity) and recent actual costs for various renewable projects (levelized power purchase agreement). The line shows the full range of estimates, while the dots and boxes show specific data points from the U.S. Energy Information Administration (EIA), the Department of Energy (DOE), and Bloomberg New Energy Finance. These data suggest that new natural gas plants are typically cheaper to build than new coal plants, and new wind plants can be cheaper to build than new gas plants, even without incentives. Recently finalized wind and solar photovoltaic installations show that with incentives, certain projects could cost less than a new gas plant.

Levelized power purchase agreements (PPAs) represent an actual contract for future prices that has been "locked-in" and includes the value of any federal and state incentives. The **levelized cost of electricity (LCOE)** represents an estimate of the per-megawatt- hour cost of building and operating an electric generating plant, taking into account the project's capital costs, operating costs, and capacity factor, among other factors. Differences in levelized cost of electricity estimates can be explained by the underlying assumptions used in each analysis. For example, it has been suggested that EIA's assumptions related to renewable technologies are more conservative than recent governments and industry reports (see Union of Concerned Scientists, May 2014, "Climate Game Changer Methodology and Assumptions," accessible at: http://www.ucsusa.org/assets/documents/global_warming/UCS-Carbon-Standards-Analysis-Methodology-and-Assumptions.pdf). All cost and price estimates displayed here were converted to $2013.

Sources: **BNEF$_a$**: Bloomberg New Energy Finance, January 2014, "H1 2014 Levelised Cost of Electricity Update;" **EIA 2014**: U.S. Energy Information Administration, May 2014, "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2014," in *Annual Energy Outlook 2014*, accessible at http://www.eia.gov/forecasts/aeo/electricity_generation.cfm; U.S. Energy Information Administration, May 2014, "Table 8.2. Cost and Performance Characteristics of New Central Station Electricity Generating Technologies," in *Annual Energy Outlook 2014*, accessible at http://www.eia.gov/forecasts/aeo/assumptions/pdf/electricity.pdf; **DOE Sunshot**: U.S. Department of Energy, February 2012, "SunShot Vision Study," accessible at: http://energy.gov/sites/prod/files/2014/01/f7/47927_chapter5.pdf; **LBNL$_a$**: M. Bolinger and S. Weaver, Lawrence Berkeley National Laborator, September 2013, "Utility-Scale Solar 2012," accessible at: http://emp.lbl.gov/sites/all/files/lbnl-6408e_0.pdf; **LBNL$_b$**: R. Wiser and M. Bolinger, Lawrence Berkeley National Laboratory, August 2014, "2013 Wind Technologies Market Report," accessible at: http://emp.lbl.gov/sites/all/files/2013_Wind_Technologies_Market_Report_Final3.pdf; **BNEF$_b$**: Bloomberg New Energy Finance, 2014, "Sustainable Energy in America Factbook", accessible at http://www.bcse.org/factbook/pdfs/2014%20Sustainable%20Energy%20in%20America%20Factbook.pdf.

Continued retirements could prompt an increase in fossil baseload generation and lead to an overall increase in CO_2 emissions from the power sector. Even if these pressures do not force nuclear capacity to retire prematurely, the nation will eventually need to replace some of these units as they reach the end of their useful lives. Stringent regulations that value low-carbon generation could help improve the economics of the existing fleet, and could potentially spur the construction of new nuclear units, particularly if increasing international development of nuclear plants leads to reductions in construction costs. Any expansion, however, will likely depend on solving the challenges of public concerns about nuclear safety and long-term waste storage.

With the confluence of low prices for natural gas and renewables, and despite any potential challenges faced by nuclear generation, the nation appears to be trending toward a lower carbon future. In a number of cases, this is happening because of market forces alone, saving consumers money. However, even where incremental costs are associated with shifting power generation, analysis suggests that net benefits are accruing to society because of associated reductions in air pollution. With the right long-term policy push, the transition could accelerate, delivering even greater public health and environmental benefits. Conversely, a lack of policy could slow down this transition and lead to continued reliance on the existing fossil fleet.

EPA is now moving forward with greenhouse gas emissions standards for existing power plants under section 111(d) of the Clean Air Act, which it projects will reduce power sector CO_2 emissions by about 27 percent below 2005 levels by 2020 and by 30 percent by 2030.[43] The health benefits of these standards alone are projected to be three to eight times the compliance costs. In total, the proposed standards are expected to result in $55 to $93 billion in climate and health benefits by 2030 at a cost of $7.3 to $8.8 billion. Given current technology trends, these estimates may actually be overly conservative, and deeper reductions may be possible at a net public benefit.

In addition, a number of studies have demonstrated that implementing an economy-wide carbon price that captures the full costs of carbon emissions can have positive impacts on economic growth depending on how the program is structured.[44]

Recommendations in Brief

- To make long-term decisions that minimize stranded assets and maximize return on investment, the industry needs long-term regulatory certainty. EPA has taken a step in this direction by proposing carbon pollution standards under section 111(d) of the Clean Air Act. Regulatory certainty could also be provided through legislative measures such as a clean energy standard, a greenhouse gas tax, or a greenhouse gas cap-and-trade program.

- The transition to a low-carbon future will be cheaper and easier with the right policy support. Specifically, we find that:

  - States and utilities should enhance access to long-term contracts by renewable energy providers, which could reduce the average electricity costs over the lifetime of typical wind and solar projects by 10–15 percent.[45]

  - Congress should stabilize federal tax credits and eliminate inefficiency in their design so that more of the value of the credit flows to project developers without increasing the cost to taxpayers.[46]

  - Financial regulators and lending institutions should work together to develop commercial investment vehicles that align the risk profile of low-carbon assets with the needs of investors in order to reduce the costs of finance.

  - States and utilities should update regulations and business models to promote a flexible power grid, allowing customers and utilities to maximize their use of low-cost variable generation such as wind and solar.

  - EPA should finalize greenhouse gas performance standards for new and existing power plants. Together, these standards will: (1) help with the nation's efforts to reduce greenhouse gas emissions; (2) deliver public health benefits through improved air quality; (3) reduce the risk of technological lock-in and stranded assets; and (4) encourage investment in natural gas generation and renewables.

  - The United States should increase federal funding for research, development, and commercialization of low-carbon and energy-saving technologies. This would help foster opportunities for American businesses and manufacturing by helping the country to remain a world leader of innovation.

REDUCING ELECTRICITY CONSUMPTION

Overview

The United States has implemented a robust and growing portfolio of regulatory and voluntary energy efficiency initiatives aimed at reducing electricity use. Together, these initiatives have helped offset total electricity demand growth, which has fallen from over 6 percent per year in the early 1970s to about 1 percent per year today as major household appliances—including refrigerators, dishwashers and clothes washers—have become 50 to 80 percent more energy efficient (Figure ES.3). New federal appliance standards implemented since 2009 alone are expected to save consumers nearly $450 billion as a result of lower electricity bills through 2030.

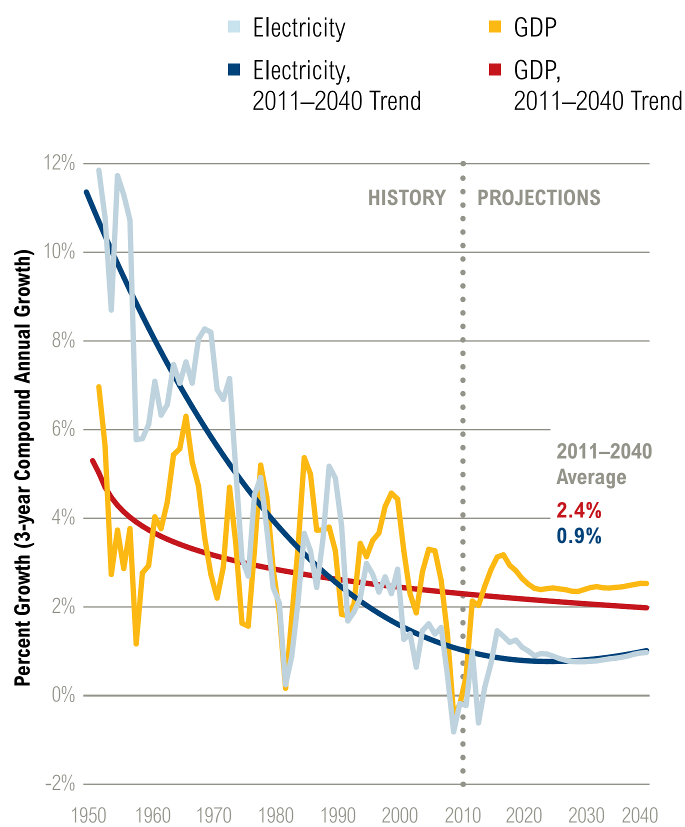
Nevertheless, research suggests that much more efficiency potential is available, and that well-designed policies can save customers money. For example, over the past decade, efficiency has remained the least-cost resource option available to utilities: levelized costs to utilities are one-half to one-third the cost of new electricity generation options. Meanwhile, state efficiency programs regularly save customers over $2 for every $1 invested, and in some cases up to $5.

The United States can continue to reduce electricity demand growth and save money for consumers and businesses in the near-to-medium term by scaling up existing initiatives. However, federal policies, including new legislation or EPA's proposed power plant standards, should be implemented to encourage more widespread adoption of ambitious state energy efficiency policies. These policies should include or be complemented by other state, federal, and local actions including: (1) updating building codes and improving their enforcement, (2) measures to promote retrofits of existing buildings, and (3) improving access to low-cost finance for efficiency projects.

Summary of Findings

A growing body of literature suggests electricity demand could be reduced 14 to 30 percent below projected levels over the next two decades while creating hundreds of billions of dollars in net savings for consumers, and significantly reducing U.S. greenhouse gas emissions.[47] In addition, retrofits that reduce building energy use in the range of 30 to 50 percent—even greater, in some cases—have been demonstrated through whole-building approaches.[48]

Figure ES.3 | **U.S. Electricity Use and Economic Growth, 1950–2040**



Source: Energy Information Administration, "U.S. Economy and Electricity Demand Growth are Linked, but Relationship is Changing," March 2013, accessible at http://www.eia.gov/todayinenergy/detail.cfm?id=10491#.

Studies suggest these money-saving opportunities exist because of the persistence of a number of market barriers to investment. For example, building owners frequently have little incentive to invest in efficiency if they do not pay the energy bills and therefore do not experience the financial benefits, thus creating split incentives. In addition, residents may not expect to capture the full lifetime benefits of an investment, thus creating ownership transfer issues. This is because residential energy efficiency measures have an average payback period of about 7 years, whereas about 40 percent of homeowners will have moved in that time. Other market barriers, including capital constraints and lack of knowledge of the lifecycle costs and benefits of products, can also prevent the implementation of cost-effective efficiency measures.

Recognizing these barriers and the financial benefits to consumers from efficiency programs, states and federal agencies have adopted a wide range of efficiency programs, several of which we profile here. Broadening and deepening these programs could deliver increased savings to consumers. For example:

- **Appliance and equipment standards, labeling, and research and development.** Customers have saved over $370 billion (net) as a result of lower utility bills from 1987 through 2012 as a result of federal appliance and equipment standards that set minimum energy efficiency levels for more than 50 products commonly used in homes and businesses.[49] Appliance and equipment standards are complemented by other federal and state initiatives, including research and development, partnerships with industry, competitions (e.g., L-prize and ENERGY STAR awards), voluntary labeling programs (e.g., ENERGY STAR and the Federal Trade Commission's EnergyGuide), and rebates and incentives for efficient appliances. Together, these programs can drive innovation and commercialization of products that are more efficient than the minimum required by standards, as has been demonstrated in many product areas including lighting, water heaters, and clothes dryers.[50] The Institute for Electric Innovation projects that pushing forward on new federal appliance and efficiency standards could reduce total electricity use by 6–10 percent below projections in 2035.[51]

- **State energy efficiency savings targets.** Twenty-four states currently have mandatory electricity savings targets that require utilities and third-party administrators to offer energy-saving programs to their customers.[52] Most state targets require incremental electricity savings of 1 percent of projected electricity sales or more each year once programs are fully ramped up, with a few requiring savings in excess of 2 percent per year. These programs regularly save customers over $2 for every $1 invested, and in some cases up to $5, which can boost local economies and create new jobs.[53] Scaling up state energy efficiency savings targets so that each state achieves savings of 2 percent annually would reduce electricity consumption in the range of 400–500 terawatt hours in 2035 (9–11 percent of total projected electricity sales),[54] and save customers tens of billions of dollars in the process.

- **State building energy codes.** Building codes help ensure that new construction and buildings undergoing major renovations and repairs meet minimum efficiency standards. According to the DOE, codes adopted between 1992 and 2012 have saved approximately 2 quads in cumulative total energy savings and are expected to net more than $40 billion in energy cost savings over the lifetime of buildings constructed during this time period.[55] To date, many states have adopted the 2007–09 codes for commercial and residential buildings. However, only about one-quarter of states have adopted the most up-to-date codes for residential and commercial buildings—which reduce building energy use by 20 and 25 percent, respectively, compared with the 2007–09 standards—leaving the door open for greater savings by other states.[b, 56]

The continued emergence of new technologies—such as high-efficiency rooftop air conditioning units, data-enabled intelligent technologies, and wide bandgap semiconductors—can create additional opportunities for savings. In 2011, DOE released a specification detailing how to build rooftop air conditioning units that use 50 percent less energy than typical models, providing the opportunity for businesses to save millions of dollars.[57, 58] So far, Daikin McQuay and Carrier have met the challenge, and three other manufacturers are still participating.[59] DOE is also working with industry to advance adoption of next-generation intelligent energy information systems and controls that provide whole-building, web-accessible data in real time. These systems allow facility managers to identify wasted energy, with the potential of cutting building electricity use by as much as 30 percent.[60] If successful, wide bandgap semiconductors could eliminate up to 90 percent of the power losses that occur in electricity conversion from AC to DC.[61]

Fully capturing existing efficiency opportunities while promoting the next wave of new technology will require policies to help overcome market barriers, and to address the inherent conflict energy efficiency presents for utility business models that tie profits to total electricity sales.

Recommendations in Brief

- The United States should scale up its existing initiatives, which are already delivering benefits many times their costs. This includes:
  - Strengthening and expanding federal appliance and equipment standards;

b. According to DOE, 10 states have adopted IECC 2012, which can achieve over 20 percent site energy savings compared with IECC 2009 and 12 states have adopted ASHRAE 90.1-2010, which can achieve 25 percent site energy savings relative to 90.1-2007.

- Enhancing efforts to deploy new technology (e.g., research and development, partnerships with industry, competitions, voluntary labeling, rebates and incentives for efficient appliances);
- Strengthening existing state energy efficiency targets, and adopting targets in states without them;
- Pursuing policies to better align utility incentive structures, such as providing performance incentives for energy efficiency, requiring utilities to consider efficiency as part of their integrated resource planning, and decoupling, among other policies.

- New federal policies should be implemented to promote the proliferation of ambitious state efficiency programs, thus expanding the number of consumers that benefit from increased energy efficiency. This could include new legislation, such as a nationwide electric energy efficiency resource standard, a clean-energy standard, and a greenhouse gas cap-and-trade program or carbon tax, including the option to recycle revenue into energy efficiency measures. EPA's proposed carbon pollution standards for existing power plants could also be an important addition to the toolkit, since they allow states to make progress toward their carbon dioxide emissions reduction targets through efficiency programs.
- Federal, state, and local governments should ensure that consumers benefit from the latest cost saving building technologies by encouraging adoption and enforcement of the most up-to-date building codes.
- Federal, state, and local governments should help unlock cost saving opportunities available through retrofits to existing buildings by (1) expanding labeling and energy assessment tools, (2) implementing building energy auditing, disclosure, and benchmarking policies, (3) recognizing the benefits of energy efficiency in mortgages, and (4) incentivizing whole-building retrofits.
- Federal, state, and local governments should take steps to improve access to low-cost financing options in order to help address barriers that might otherwise be created by high up-front costs. Specifically, they should: (1) stimulate private funding; (2) improve access to PACE financing; and (3) pursue other innovative financing options (e.g., by establishing "green banks").

CLEANER AND MORE FUEL EFFICIENT PASSENGER VEHICLES

Overview

New standards for passenger cars and light-duty trucks[62] will roughly double the fuel economy of model year 2025 vehicles, while delivering lower costs to consumers, improved air quality, and increased energy security because of lower oil demand. Once fully implemented, owners are expected to save on average $3,400 to $5,000 (net) over the life of the vehicle (compared with model year 2016 vehicles).

Meanwhile, steady advances in electric vehicle battery technology and the anticipated roll out of fuel cell vehicles in the 2015–17 timeframe hint that the automobile industry may be on the brink of an even greater transition. For example, battery prices have fallen by more than 40 percent since 2010. Some industry analysts are predicting that long-distance electric vehicles will be cost-competitive with internal-combustion-engine vehicles (because of fuel price savings) by the early 2020s, even without federal incentives.[63] Meanwhile, several large automakers continue to pursue fuel cells for light-duty vehicles, with commercialization expected in 2015–17.

However, for these next generation technologies to fully take hold, they need to overcome a variety of barriers, including a lack of charging infrastructure, drivers' range anxiety, and higher upfront costs (even if lifetime costs are lower). This will likely require continued support at the local, state, and federal levels as these new technologies mature through initiatives such as continued research and development, vehicle incentives and mandates, expansion of fueling and charging stations, and technology standardization.

Summary of Findings

New greenhouse gas and fuel economy standards established by the EPA and the U.S. Department of Transportation (DOT) will make model year 2025 vehicles roughly twice as fuel efficient as similar sized vehicles sold in the United States today. The resulting lower fuel costs will save model year 2025 vehicle owners on average $3,400 to $5,000 net over the life of their vehicle compared with model year 2016 vehicles.[64] The entire program for model years 2017–25 builds on standards set for model years 2012–16 and is estimated to produce net savings of $186 to $291 per metric ton of CO_2 reduced in 2030 and 2050, respectively.

These standards will also help reduce America's dependence on oil by more than 2 million barrels per day in 2025 (which could help reduce U.S. oil imports) and result in $3.1 to $9.2 billion in benefits (net present value) from reducing non-greenhouse gas air pollutants.[65] Notably, the EPA and DOT standards will leverage technical progress being made abroad because other countries are requiring large increases in fuel economy over time—the European Union and Japan, for example, have more ambitious standards.[c]

The rapid change in vehicle fuel efficiency required under the EPA and DOT greenhouse gas emissions and fuel economy standards is not new to the automobile industry. Over the past 40 years, engine efficiency has improved considerably.[66] Since the late 1980s, however, the majority of automobile improvements were to make larger, faster, more rapidly accelerating vehicles rather than to decrease fuel consumption.[67]

Since the new vehicle standards went into effect, improvements have taken place across vehicle types. The number of sport utility vehicles with a fuel economy of at least 25 miles per gallon has doubled, while the number of car models with a fuel economy of at least 40 miles per gallon has increased sevenfold.[68] This increase in fuel efficiency has been driven by a surge in the deployment of off-the-shelf technologies, such as variable valve timing, gasoline direct injection, turbochargers, six- and seven-speed transmissions, and others detailed in Chapter 3.

Beyond conventional cars, next-generation technologies, such as electric and plug-in hybrid electric vehicles, have begun entering the marketplace at a significant rate. At the end of 2013, electric and plug-in hybrid electric vehicles accounted for about 1.3 percent of total passenger car sales, almost double the number sold in 2012.[69] While electric and plug-in hybrid vehicle sales may seem modest compared with the size of the U.S. fleet, the uptake of electric vehicles has been much faster than the initial uptake of hybrid vehicles in the United States. Looking forward, sales of these vehicles are likely to increase—a multistate zero-emission vehicle mandate and memorandum of understanding among California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, and Vermont (accounting for 23 percent of the U.S car market) is projected to put at least 3.3 million zero-emission vehicles on the road by 2025.[70] To ensure this target is met, the states will coordinate on key actions, such as educating consumers; providing driver incentives; increasing the number of zero-emission vehicles in state, municipal, and other public fleets; and promoting workplace charging, among other actions.[71]

Increased deployment of electrified vehicles, along with technological improvements, has helped drive a rapid decline in the price for advanced battery systems. This trend is likely to continue as Tesla Motors plans to build facilities by 2017 that reportedly will produce batteries that are 30 percent cheaper than today's batteries.[72] Some electrified vehicle models now have lifetime costs lower than comparable conventional vehicles when including federal incentives of $7,500 per vehicle.[73] Because battery costs make up a large portion of the upfront costs for plug-in hybrids and electric vehicles, both the upfront costs and total cost of ownership of electric vehicles could come down significantly as battery prices decrease. Some industry analysts predict that long-distance electric vehicles will be cost-competitive (when taking into account fuel savings over five years) with conventional combustion engine vehicles, even without federal incentives, by the early 2020s.

Hydrogen fuel-cell vehicles are beginning to show potential as well. Several large automakers are pursuing fuel cell powered vehicles, with early commercialization expected in 2015–17.[74] Hydrogen fuel cell systems can achieve greater energy density than lithium ion batteries, theoretically allowing them to achieve longer ranges than electric vehicles and making them a better fit for larger vehicles that require more power. In addition, their use of a liquid fuel gives them a fueling time similar to conventional vehicles. While prices for these vehicles have yet to be released, the costs for fuel cells continue to decline. DOE expects prices to hit $40 per kilowatt by 2020 with an ultimate goal of $30 per kilowatt,[75] at which point DOE expects fuel cells to become cost competitive with internal combustion engines.[76]

Despite this progress, challenges remain for alternative fuel vehicles. Electric vehicles have limited range and charging infrastructure, as well as longer charging time than consumers are used to spending refueling gasoline or diesel vehicles. Electric vehicles currently on the market have a range of 84 to 265 miles,[77] which can be affected by driving style, cargo load, and weather conditions, especially cold weather.[78] These shorter ranges can induce anxiety among drivers, particularly when the charging

c. Note, however, that vehicles in some countries are smaller, lighter, and have lower performance compared with vehicles sold in the United States.

infrastructure is limited. While there were over 8,500 public electric charging stations as of July 2014,[79] this is only a small fraction of the number of gasoline stations in the United States (roughly 160,000).[80]

Limited range and long refueling times are not a problem for fuel-cell vehicles, but they too face challenges of limited fueling infrastructure because of the network effects of alternative fuel vehicles. There are currently only 12 public hydrogen filling stations, 10 in California and 1 each in South Carolina and Connecticut.[81] But steps are being taken to address this limitation. California expects to have 51 stations operating by the end of 2015, and other states are making progress as well.[82]

The actual greenhouse gas benefit of electric and hydrogen vehicles compared with gasoline and diesel fuels could be big or small depending on the carbon intensity of the production of those fuels. By comparison, natural gas vehicles could actually be worse from a greenhouse gas perspective because of methane emissions from natural gas production, processing, and transmission. Even if the rate is reduced considerably, the benefit of switching cars from gasoline to natural gas will remain more limited than the benefit of switching electricity generation from coal to gas.

The current standards (finalized in 2012) will roughly double the fuel economy of new cars by 2025. If technological progress continues, it should be easier and more cost-effective to meet the model year 2025 standards, and might be possible to achieve even deeper reductions than required by current standards. Technological progress could also lead to greater improvements in fuel economy beyond 2025. The National Academy of Sciences found that working toward reducing light-duty vehicle CO_2 emissions by 80 percent below 2005 levels could lead to $670 billion to $2.3 trillion in net savings from reduced fuel costs (net present value).[83] Realizing these goals depends heavily on the rate of technological progress, which the academy concludes will require "strong and effective policies emphasizing research and development, subsidies, energy taxes, or regulations in order to overcome cost and consumer choice factors."

Recommendations in Brief

- Corporate average fuel economy (CAFE) standards and greenhouse gas emissions standards are poised to deliver significant benefits to consumers as a result of lower ownership costs and improved air quality. Depending on the progress of technology over the coming years, these standards may warrant strengthening.

- In the meantime, complementary policies by federal, state, and local governments can help promising technologies realize their potential:

  - Increase the number of alternative fuel stations (e.g., electricity and hydrogen) to help ease drivers' range anxiety and provide the certainty auto companies need to commit to manufacturing alternative-fuel vehicles.

  - Charging options should be improved by eliminating barriers to access and adopting communication standards for controlled charging by grid operators. This would allow electric vehicle charging to better align with periods of high generation from variable renewable resources and provide low-cost grid stabilization as well as reduce charging costs for electric vehicle owners.

  - Research and development for next-generation technologies should be expanded to help the United States take a leadership position in alternative vehicle manufacturing.

  - Federal and state mandates and incentives to promote sales of alternative vehicles should be sustained and expanded to help accelerate the technology learning curve and bring lower-cost alternative vehicles to market faster.

IMPROVED PRODUCTION, PROCESSING, AND TRANSMISSION OF NATURAL GAS

Overview

Methane, the primary component of natural gas, is a potent greenhouse gas, with at least 34 times the global warming power of carbon dioxide.[84] Methane emissions occur throughout the natural gas life cycle. Without additional policies, methane emissions from natural gas systems are expected to grow 4.5 percent by 2018, and to continue to grow slowly over the coming decades.[85] Leaks and vents of natural gas occur throughout the natural gas supply chain, from drilling the well through production, processing, transmission, and distribution.[d] These emissions erode the greenhouse gas advantage natural gas has over other fossil fuels used for electricity generation and transportation. Beyond benefitting the climate, reducing methane emissions is often good for business because companies can bring more product to market, and because it presents positive human health and environmental co-benefits through concomitant reductions in smog-forming and toxic carcinogenic emissions.[86]

Summary of Findings

Dozens of proven technologies that minimize leaks and vents of methane are currently available and deployed across the United States. However, their use remains uneven largely because of market barriers that impair the ability of drillers and other service providers to capture the increased revenue by changing equipment and practices. These barriers include:

- **Principal-Agent Problems:** Thousands of companies are active in the U.S. natural gas industry, from contractors that drill wells to pipeline operators to the local utilities that operate the million-plus miles of small distribution pipelines. With so many independent actors, the incentives for investment in emissions control technologies are not always well aligned, as those companies that make investments in technologies that reduce the amount of methane emitted are not always the same companies that reap the benefits of those investments.

- **Imperfect Information:** Because emissions measurement technology is still expensive and not widely used, many companies do not have a complete picture of how much methane they are emitting, and from which sources. Most companies, therefore, are not aware how much money they can save by investing in technologies that reduce methane emissions.

- **Opportunity Costs:** Investing capital or engineering capacity in equipment to reduce or eliminate natural gas leaks represents an opportunity cost for owners and operators of natural gas systems. Investments in projects that reduce wasted natural gas compete with other potential investments, primarily the drilling of new production wells or other measures to increase natural gas production. Even though most emissions-control technologies pay for themselves in three years or less, that may not compare favorably to other investment opportunities.

While some companies active throughout the natural gas supply chain—from production through distribution—have already recognized the economic advantages of investing in technologies that reduce methane emissions, many have not. Voluntary measures reduce about 20 percent of methane emissions from natural gas systems, according to EPA.[87] But existing voluntary measures merely skim the surface of available, cost-effective emissions reduction opportunities, according to recent studies from ICF International and the Natural Resources Defense Council (NRDC).[88] This suggests the states and the federal government have ample opportunity to implement additional standards requiring reductions in methane emissions to overcome these barriers.

EPA's 2012 standards to reduce emissions of hazardous air pollutants, sulfur dioxide (SO_2), and volatile organic compounds are expected to significantly reduce methane emissions, saving the industry approximately $10 million in 2015 because the value of the avoided emissions of natural gas is greater than the cost of equipment to capture it (annual savings are estimated at $330 million versus $320 million in compliance costs). Importantly, these savings do not consider the benefit of reducing methane emissions and conventional air pollutants. EPA estimates that the standards will reduce emissions of volatile organic compounds by 172,000 metric tons in 2015 alone.[89] Some studies have found that the health benefits due to improved air quality could be as high as $2,640 per metric ton of volatile organic compounds nationwide, with even higher benefits in some localities.[90]

A growing number of studies suggest, however, that the EPA rules have left considerable cost saving opportunities on the table. A significant fraction of methane emissions not currently addressed could be reduced with existing technologies, according to studies from ICF International and NRDC. For example, ICF estimates that over 20 percent of the remaining methane emissions from onshore gas development (after the EPA air quality standards) can be reduced while producing net savings, and a further 40

d. In this report, "natural gas systems" refers to the production of natural gas from natural gas wells, as well as the processing, transmission, and distribution of that gas. Natural gas produced at oil wells is not included. Similarly, the end use of natural gas—for electricity generation, transportation, residential heating, or other purposes—is not included, though the use of natural gas for electricity generation and in the transportation sector is covered in other chapters.

percent of emissions can be reduced at an average cost of just $0.01 per thousand cubic feet of natural gas produced (by comparison, daily spot prices for natural gas averaged around $4 per thousand cubic feet over the two years ending September 2014).[91] The NRDC study showed even greater levels of negative cost opportunity. They found that moving the entire industry to use best practices would reduce U.S. greenhouse gas emissions by approximately 150 million metric tons of CO_2 equivalent in 2020. Moreover, these measures would generate revenue of around $1.5 billion annually from delivering more natural gas to market.[e] Notably, neither ICF International's nor NRDC's estimates include the ancillary benefits of reduced greenhouse gas emissions and cleaner air from reductions in volatile organic compounds and other traditional pollutants that are co-emitted with methane. Therefore, it is likely that even greater reductions are possible at net public benefit.

Of course, the value of captured natural gas depends on its market price. From 2000 through 2010, natural gas prices were highly volatile, with monthly average spot prices ranging from about $2 to $13.75 per thousand cubic feet.[92] While recent increases in supply have put downward pressure on prices and moderated much of the volatility, many industry analysts predict prices to increase by about 20 percent through 2020.[93] If those price increases materialize, capturing and selling any natural gas that is leaked, vented, or flared (that is, combusted at the wellhead) would be even more profitable, reducing the payback period for investments in emissions control technologies.[f] As natural gas production grows over the coming decades, there will be a growing need to address methane emissions from new and existing infrastructure, but also more opportunity to do so.

Recommendations in Brief

- Emissions standards for natural gas systems should be implemented or strengthened to help correct the market failures that leave many cost-saving opportunities on the table. These standards could be achieved through section 111 of the Clean Air Act, through Congressional legislation, or through standards implemented at the state level.
- Agencies like the Federal Energy Regulatory Commission and EPA should work with industry to revise contracts in such a way that service providers throughout the natural gas supply chain share in the benefits of reducing waste and increasing the amount of natural gas brought to market.
- The Department of Energy should work to improve emissions measurement and control technologies through continued research and development. Reducing the cost of this equipment will further encourage voluntary measures to reduce emissions, and lower the cost of complying with future standards from EPA.
- The Pipeline and Hazardous Materials Safety Administration could require stricter inspection and maintenance standards for gathering, transmission, and distribution systems, which would improve safety and increase industry revenues while reducing methane emissions from those sectors.

REDUCING EMISSIONS OF HIGH GLOBAL WARMING POTENTIAL HYDROFLUOROCARBONS

Overview

Hydrofluorocarbons (HFCs) are a small but rapidly growing component of U.S. greenhouse gas emissions. These gases, commonly used as refrigerants, foam blowing agents, and aerosols, can have very high global warming potentials (GWPs). Those with the highest GWPs trap thousands of times more heat than CO_2. Their use is on the rise as a result of the phase-out of their ozone-depleting predecessors, hydrochlorofluorocarbons (HCFCs).[94] However, alternatives with low, and even near-zero, global warming potential are increasingly becoming available. They include natural refrigerants such as CO_2 or hydrocarbons (HCs) as well as hydrofluoroolefins (HFOs), which contain hydrogen, fluorine, and carbon like HFCs, but have much lower GWPs.[95] Some of these alternatives also offer performance benefits (via superior thermodynamic efficiency) compared with the higher-GWP HFCs they could replace, lowering the amount of electricity consumed and thereby reducing electricity bills and GHG emissions. New policies could spur uptake of new cost-effective alternatives, while driving the continued research and development of new alternatives.

e. The revenue estimate cited here reflects updated data from the latest greenhouse gas inventory, and is based on a natural gas price of $4 per thousand cubic feet.

f. Payback periods can vary depending on the cost of the emissions control technology and the prevailing price of natural gas.

Summary of Findings

HFC manufacturers, like Honeywell, Arkema, and DuPont, already produce a variety of low-GWP alternatives, including HFOs and HFO blends, for use in automobiles, supermarkets, home air conditioning, commercial chillers, refrigerators, coolers, and other appliances and equipment. Several companies have begun using these and other alternatives, finding them as effective as high-GWP HFCs, and, in some cases, finding they provide benefits such as improved energy efficiency and net financial savings over the lifetime of the equipment. No single solution works across the many end-use applications, but innovation is occurring. For example:

- Sobeys, a Canadian supermarket chain, found that while the cost of a CO_2 transcritical system[96] (which has benefits in cold to moderate climates) is around 11 percent more than a conventional system, the added cost is repaid within three years.[97]
- Coca-Cola uses CO_2 in 1 million HFC-free coolers and aims to purchase only CO_2-based equipment by 2015.[98] Because of its transition to CO_2-based technology for new equipment, Coca-Cola has improved its cooling equipment energy efficiency by 40 percent since 2000, and reduced its direct greenhouse gas emissions by 75 percent.[g, 99]
- Coolers introduced by PepsiCo, Red Bull, Heineken, and Ben & Jerry's are based on hydrocarbons including propane (R-290) or isobutane (R-600a). These companies combined have more than 600,000 units in use today and have seen energy efficiency improvements from 10 to 20 percent or even greater.[100]
- Fifteen car companies, including General Motors, Ford, and Chrysler, are moving forward with HFO-1234yf,[101] a new low-GWP refrigerant for personal vehicle air conditioners that has a GWP 99.9 percent lower than the HFC it replaces.[102] An estimated 1 million cars on the road worldwide already use this low-GWP refrigerant.[103] This number is expected to grow to nearly 3 million by the end of 2014.[104]
- The Consumer Goods Forum, a CEO-level organization formed in 2009 of 400 global consumer goods manufacturers and retailers with combined revenue in excess of $2.8 trillion, has agreed to begin phasing out HFC refrigerants in 2015 and replacing them with non-HFC refrigerants.[105]

These cases are not unusual. In a recent analysis, EPA found that the nation could reduce annual emissions of HFCs by 20 percent below business-as-usual estimates in 2020, and 42 percent in 2030 through alternatives that pay for themselves over the life of the equipment.[106] This is largely the result of considerable technological progress over the past several years to make low-GWP alternatives available.

Options are available today to reduce the majority of HFC emissions across most major source categories, and more technologies in the pipeline should become available within the next five years.[107] For example, Honeywell recently announced plans to expand manufacturing of HFO refrigerants, blowing agents, and aerosol propellants in the United States,[108] and Arkema has announced it will construct HFO production facilities.[109] DuPont is producing HFOs and is working on a new foam expansion agent based on HFO technology, as well as various HFO products for refrigeration and air conditioning applications.[110] As HFO production scales up, costs for these low-GWP alternatives are anticipated to decline. This would likely result in more widespread use of these alternatives as well as development of more new technology, which could drive prices even lower. For example, once Heineken started purchasing HFC-free coolers at a large scale, their cost dropped by 15 percent. Now they say that the main barriers they face to more widespread use of the new technology are legal, such as the need for approval of HFC alternatives, rather than cost barriers.[111]

However, adoption of existing low-GWP alternatives remains uneven at best, for a variety of reasons. Although converting to some low-GWP alternatives may offer net cost savings, it may involve higher upfront costs, or require the replacement of existing equipment, or even the redesign of a facility or vehicle.[112] Additionally, customers who purchase refrigeration or air conditioning equipment may not be educated on the availability and benefits of low-GWP alternatives. Thus, there is little reason to believe that the U.S. market will rapidly move to these alternatives without new rules or other incentives that drive their adoption.

g. Note, CO_2 transcritical technology has temperature limitations and works most efficiently in cold to moderate climates.

Momentum toward this end appears to be building at the international level. The proposed North American amendment to the Montreal Protocol, which would reduce HFC consumption 85 percent by 2035 compared with 2008–10 levels,[113] is now supported by more than 100 nations.[114] Producers and consumers of HFCs also support a global phase-down. For example, the Alliance for Responsible Atmospheric Policy, an industry coalition composed of manufacturers and businesses which rely on HCFCs and HFCs, supports a planned, orderly global phase-down of high-GWP substances, while improving energy efficiency, leakage reduction, and recovery/reuse or destruction at the application's end-of-life.[115] In the meantime, much can be done domestically to reduce emissions of high-GWP HFCs.

Sustained deep reductions of high-GWP HFCs, however, will require continued technological progress and regulatory responsiveness, and may require transitioning to alternatives that will not pay for themselves in the short term.

Recommendations in Brief

- The United States should continue to work to achieve an international phase-down of the consumption of high-global-warming-potential (GWP) hydrofluorocarbons (HFC) through amendments to the Montreal Protocol.

- In the meantime, EPA and Congress can take the following steps to reduce domestic emissions of high-GWP HFCs:

  - EPA should use its authority under its Significant New Alternatives Policy program (SNAP) through section 612 of the Clean Air Act. This includes finalizing proposed regulations to delist some uses of high-GWP HFCs and continuing to phase down HFCs where safer, cost-effective alternatives exist. This will help harness win-win opportunities. EPA previously estimated that HFC emissions could be reduced by over 40 percent from what would otherwise be emitted in 2030 entirely through measures that come at a negative or break-even price today.

  - EPA should work toward ensuring that the alternatives development process moves swiftly and that new chemicals are quickly, yet thoroughly, tested for their safety and performance. EPA should also finalize its proposed regulation to list new alternatives and continue evaluating and approving appropriate low-GWP alternatives.

  - EPA should extend the servicing and disposal of air conditioning and refrigeration equipment requirements for HCFCs and CFCs to HFCs (under section 608 of the Clean Air Act) as well as increase initiatives for HFC reclamation and recycling to ensure that fewer virgin HFC compounds are used until they are phased down.[116]

  - Over time, it may also be appropriate to implement a flexible program to reduce emissions of high-GWP HFCs either by EPA under section 615 of the Clean Air Act or via Congressional legislation, as the flexibility provided by these programs could allow for deeper reductions in a cost-effective manner.

ENDNOTES

1. National Climatic Data Center, "Global Land and Ocean Temperature, July," Climate at a Glance, August 2014, accessible at http://www.ncdc.noaa.gov/cag/time-series/global.
2. U.S. Global Change Research Program, 2014 National Climate Assessment, "Extreme Weather,"U.S. Global Change Research Program, 2014, accessible at http://nca2014.globalchange.gov/highlights/report-findings/extreme-weather.
3. T. Peterson, P. Stott, S. Herring, "Explaining Extreme Events of 2011 from a Climate Change Perspective," National Climatic Data Center, May 4, 2012, accessible at http://www1.ncdc.noaa.gov/pub/data/cmb/bams-sotc/2011-peterson-et-al.pdf.
4. Nicholas Stern, 2006, "Executive Summary," *Stern Review: The Economics of Climate Change*, accessible at http://webarchive.nationalarchives.gov.uk/20130129110402/http://www.hm-treasury.gov.uk/d/Executive_Summary.pdf.
5. Executive Office of the United States of America, 2014, "The Cost of Delaying Action to Stem Climate Change," July, accessible at http://www.whitehouse.gov/sites/default/files/docs/the_cost_of_delaying_action_to_stem_climate_change.pdf.
6. P. Hibbard, S. Tierney, A. Okie, P. Darling, "The Economic Impacts of the Regional Greenhouse Gas Initiative on Ten Northeast and Mid-Atlantic States," Analysis Group, November 15, 2011, accessible at http://www.analysisgroup.com/uploadedFiles/Publishing/Articles/Economic_Impact_RGGI_Report.pdf.
7. Public Service Commission of Wisconsin and Cadmus Group, 2013, "Focus on Energy Calendar Year 2012 Economic Impacts Report, "accessible at https://focusonenergy.com/sites/default/files/FOE_XC_CY12_EconomicImpacts-Final_24JAN2014.pdf.
8. These ranges are based on lifetime net present value with 7 and 3 percent discount rates, respectively, using 2010 dollars. While more efficient vehicles are expected to cost more than their counterparts, EPA estimates that fuel savings from model year 2025 vehicles will offset the higher vehicle cost in less than 3.5 years when those vehicles are purchased outright by the consumer. However, consumers that purchase their new model year 2025 vehicle with a standard five-year loan will benefit right away as fuel savings offset loan repayment by $12 each month.
9. American Council for an Energy-Efficient Economy, "Fuel Economy Standards Bring Major Oil Savings Benefits," Fact Sheet, September 2013, accessible at http://www.aceee.org/files/pdf/fact-sheet/cafe-fact-sheet.pdf.
10. U.S. Environmental Protection Agency, 2012, "Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews," Final Rule, 40 CF Part 63 (EPA-HQ-PA-2012-0505), accessible at http://www.epa.gov/airquality/oilandgas/pdfs/20120417finalrule.pdf.
11. A. Markandya and N. Dale, 2012, "The Montreal Protocol and the Green Economy: Assessing the Contributions and Co-Benefits of a Multilateral Environmental Agreement," Contribution to the Green Economy Initiative, United Nations Environment Programme, OzonAction Branch and Economics and Trade Branch, accessible at http://www.unep.org/ozonaction/Portals/105/documents/publications/green-economy-report.pdf.
12. U.S. Energy Information Administration, 2014, "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2014," *Annual Energy Outlook 2014*, accessible at http://www.eia.gov/forecasts/aeo/electricity_generation.cfm; U.S. Energy Information Administration, 2014. "Table 8.2. Cost and Performance Characteristics of New Central Station Electricity Generating Technologies," Annual Energy Outlook 2014, accessible at http://www.eia.gov/forecasts/aeo/assumptions/pdf/electricity.pdf, Bloomberg New Energy Finance, January 2014, "H1 2014 Levelised Cost of Electricity Update"
13. The Business Council for Sustainable Energy, 2014, *Sustainable Energy in America Factbook*, Bloomberg New Energy Finance, February, accessible at http://www.bcse.org/factbook/pdfs/2014%20Sustainable%20Energy%20in%20America%20Factbook.pdf.
14. Bob Fagan, Patrick Luckow, David White, and Rachel Wilson, 2013, "The Net Benefits of Increased Wind Power in PJM," Synapse Energy Economics, Inc., May, accessible at http://www.synapse-energy.com/Downloads/SynapseReport.2013-05.EFC.Increased-Wind-Power-in-PJM.12-062.pdf; Bob Fagan, Max Chang, Patrick Knight, Melissa Schultz, Tyler Comings, Ezra Hausman, and Rachel Wilson, 2012, "The Potential Rate Effects of Wind Energy and Transmission in the Midwest ISO Region," Synapse Energy Economics, Inc., May, accessible at http://cleanenergytransmission.org/wp-content/uploads/2012/05/Full-Report-The-Potential-Rate-Effects-of-Wind-Energy-and-Transmission-in-the-Midwest-ISO-Region.pdf; D. Lew, and G. Brinkman, 2013, "The Western Wind and Solar Integration Study Phase 2: Executive Summary," National Renewable Energy Laboratory, September, accessible at http://www.nrel.gov/docs/fy13osti/58798.pdf; Josh Ryor and Letha Tawney, 2014, "Shifting to Renewable Energy Can Save U.S. Consumers Money," World Resources Institute, June, accessible at http://www.wri.org/blog/2014/06/shifting-renewable-energy-can-save-us-consumers-money.
15. L. Tillemann, 2013, "Revolution Now: The Future Arrives for Four Clean Energy Technologies," U.S. Department of Energy, September, accessible at http://energy.gov/sites/prod/files/2013/09/f2/Revolution%20Now%20--%20The%20Future%20Arrives%20for%20Four%20Clean%20Energy%20Technologies.pdf.
16. Ibid.
17. U.S. Department of Energy, 2013, "Wide Bandgap Semiconductors: Pursuing the Promise," Fact Sheet, DOE/EE-0910, April 2013, DOE Office of Energy Efficiency & Renewable Energy, Advanced Manufacturing Office, accessible at http://www1.eere.energy.gov/manufacturing/rd/pdfs/wide_bandgap_semiconductors_factsheet.pdf.
18. U.S. Environmental Protection Agency, 2013, "Global Mitigation of Non-CO_2 Greenhouse Gases: 2010–2030," Executive Summary, April 2014, EPA Office of Atmospheric Programs, Washington, DC, accessible at http://www.epa.gov/climatechange/EPAactivities/economics/nonco2mitigation.html.
19. Atmosphere ASIA, "Summary Report: Technology & Innovation: Natural Refrigerants," presentation in Tokyo, Japan, February 2014, accessible at: http://www.atmo.org/presentations/files/401_atmo_Asia_report_2014_final_small.pdf.
20. U.S. Environmental Protection Agency, 2013, "Benefits of Addressing HFCs under the Montreal Protocol," June, EPA, Stratospheric Protection Division, Office of Atmospheric Programs, Office of Air and Radiation, Washington, DC, accessible at http://www.epa.gov/ozone/downloads/Benefits_of_Addressing_HFCs_Under_the_Montreal_Protocol_6-21-2013.pdf.
21. Cost estimates were converted from 2007 dollars to 2013 dollars. See: Interagency Working Group on Social Cost of Carbon, United States Government, "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis—Under Executive Order 12866," Technical Support Document, May 2013, and "Revised Social Cost of

CO_2, 2010–2050 (in 2007 dollars per metric ton of CO_2),” accessible at http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf.
22. Ibid.
23. M. Bolinger, “An Analysis of the Costs, Benefits, and Implications of Different Approaches to Capturing the Value of Renewable Energy Tax Incentives,” May 2014, accessible at http://eetd.lbl.gov/sites/all/files/lbnl-6610e_0.pdf.
24. The Alliance for Responsible Atmospheric Policy recently petitioned EPA to extend the rules on air conditioning and refrigerant management in section 608 of the Clean Air Act to HFCs (See Alliance for Responsible Atmospheric Policy, “Petition to Extend the Requirements of 40 C.F.R. Part 82, Subpart F to HFCs,” January 2014, accessible at http://www2.epa.gov/sites/production/files/2014-05/documents/alliance-petition-31jan2014-v2-2.pdf). This action is also included in the proposed Senate bill, the Super Pollutants Act of 2014 (See “Super Pollutants Act of 2014,” accessible at http://www.murphy.senate.gov/download/super-pollutants-act_-bill-text?id=be4ed0be-4cef-49d9-aaa2-338cdebfceba&download=1).
25. U.S. Energy Information Administration, “Table 12.6 Carbon Dioxide Emissions From Energy Consumption: Electric Power Sector,” *Monthly Energy Review* , August 2014, accessible at http://www.eia.gov/totalenergy/data/monthly/pdf/sec12_9.pdf.
26. Since 2000, the United States has primarily built lower-carbon resources, constructing 249 gigawatts of gas, along with 57 gigawatts of wind, and only 18 gigawatts of coal. Includes new capacity built for the electric utility sector and independent power producers between 2000 and 2012. See U.S. Energy Information Administration (EIA), Electricity: “Form EIA-860 detailed data,” Final 2012 data, October 2013, accessible at http://www.eia.gov/electricity/data/eia860/.
27. Shakeb Afsah and Kendyl Salcito, “Demand Reduction Slashes US CO_2 Emissions in 2012,” CO_2 Scorecard, May 2013, accessible at: http://co2scorecard.org/home/researchitem/27.
28. U.S. Energy Information Administration. “Table 6.7.A. Capacity Factors for Utility Scale Generators Primarily Using Fossil Fuels, January 2008–May 2014,” *Electric Power Monthly*, May 2014, accessible at http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_6_07_a.
29. U.S. Energy Information Administration, “Table 1.1. Net Generation by Energy Source: Total (All Sectors), 2004-May 2014,” *Electric Power Monthly*, July 28, 2014, accessible at http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_1.
30. Bob Fagan, Patrick Luckow, David White, and Rachel Wilson, 2013, “The Net Benefits of Increased Wind Power in PJM,” Synapse Energy Economics, Inc., May, accessible at http://www.synapse-energy.com/Downloads/SynapseReport.2013-05.EFC.Increased-Wind-Power-in-PJM.12-062.pdf; Bob Fagan, Max Chang, Patrick Knight, Melissa Schultz, Tyler Comings, Ezra Hausman, and Rachel Wilson, 2012, “The Potential Rate Effects of Wind Energy and Transmission in the Midwest ISO Region,” Synapse Energy Economics, Inc., May, accessible at http://cleanenergytransmission.org/wp-content/uploads/2012/05/Full-Report-The-Potential-Rate-Effects-of-Wind-Energy-and-Transmission-in-the-Midwest-ISO-Region.pdf; D. Lew, and G. Brinkman, 2013, “The Western Wind and Solar Integration Study Phase 2: Executive Summary,” National Renewable Energy Laboratory, September, accessible at http://www.nrel.gov/docs/fy13osti/58798.pdf; Ryor and Tawney, 2014, “Shifting to Renewable Energy Can Save U.S. Consumers Money.”
31. The most recent contracts approved by the commission for new wind capacity have levelized costs in the $50 to $59 per megawatt hour range. The commission reports that new coal projects have a levelized cost of $133 per megawatt hour. Thus, even without the federal tax credit (up to $23 per megawatt hour), these wind projects would still be cheaper than new coal plants. See J. Quackenbush, G.White, S.Talberg, “Report on the Implementation of the P.A. 295 Renewable Energy Standard and the Cost-Effectiveness of the Energy Standards,” Michigan Public Service Commission, February 14, 2014, p. 30, accessible at http://www.michigan.gov/documents/mpsc/pa295report_447680_7.pdf.
32. Eric Wesoff, “Austin Energy Switches From SunEdison to Recurrent for 5-Cent Solar,” GreenTech Media, May 2014, accessible at http://www.greentechmedia.com/articles/read/Austin-Energy-Switches-From-SunEdison-to-Recurrent-For-5-Cent-Solar.
33. MidAmerican Energy, “MidAmerican Energy Announces $1.9 Billion Investment in Additional Wind Generation Capacity,” May 8, 2013, accessible at http://www.midamericanenergy.com/wind_news_article.aspx?id=634.
34. For example, PJM, National Renewable Energy Laboratory (NREL) for the Western United States, and the state of Michigan have all found that 30-35 percent of electricity could be generated using variable renewable resources with minimal cost. See GE Energy Consulting, “PJM Renewable Integration Study Executive Summary Report,” Revision 05, 2014, accessible at http://pjm.com/~/media/committees-groups/task-forces/irtf/postings/pris-executive-summary.ashx; GE Energy, Prepared for National Renewable Energy Laboratory, 2010, “Western Wind and Solar Integration Study,” accessible at http://www.nrel.gov/docs/fy10osti/47434.pdf; J.D. Quackenbush and S. Bakkal, 2013, “Readying Michigan to Make Good Energy Decisions: Renewable Energy,” Michigan Public Service Commission, Licensing and Regulatory Affairs. Michigan Economic Development Corporation, accessible at http://www.michigan.gov/documents/energy/renewable_final_438952_7.pdf.
35. L. Bird, M. Milligan, and D. Lew, 2013, “Integrating Variable Renewable Energy: Challenges and Solutions,” Technical Report, National Renewable Energy Laboratory, September, accessible at http://www.nrel.gov/docs/fy13osti/60451.pdf.
36. According to DOE, “more than 2,300 circuit miles of new transmission additions were constructed per year, with an additional 18,700 circuit miles planned over the next five years. By comparison, transmission was being constructed at a rate of about 1,000 circuit miles per year as recently as five years ago” Ryan Wiser and Mark Bolinger, “2012 Wind Technologies Market Report,” U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, accessible at http://emp.lbl.gov/sites/all/files/lbnl-6356e.pdf; Bird et al., “Integrating Variable Renewable Energy: Challenges and Solutions.”
37. American Wind Energy Association has identified near-term transmission projects which could integrate almost 70 gigawatts of additional wind capacity if all projects were completed. See Wiser and Bolinger, “2012 Wind Technologies Market Report.”
38. For more information, see M. M. Hand, S. Baldwin, E. DeMeo, J. M. Reilly, T. Mai, D. Arent, G. Porro, M. Meshek, D. Sandor (eds.), *Renewable Electricity Futures Study*, 4 vols. NREL/TP-6A20-52409, Golden, CO: National Renewable Energy Laboratory, accessible at http://www.nrel.gov/analysis/re_futures/.
39. U.S. Energy Information Administration, “Table 7.2b Electricity Net Generation: Electric Power Sector,” *Monthly Energy Review*, August 2014, accessible at http://www.eia.gov/totalenergy/data/monthly/index.cfm.

40. U.S. Environmental Protection Agency, "Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units," Proposed Rule, pp. 151–52, June 18, 2014, accessible at http://www.gpo.gov/fdsys/pkg/FR-2014-06-18/pdf/2014-13726.pdf.
41. According to EIA, four nuclear units closed in 2013 with additional closures announced for 2014, including Entergy's Vermont Yankee plant. U.S. Energy Information Administration, 2014, "Table 8.1: Nuclear Energy Overview," *Monthly Energy Review*, June 2014, accessible at http://www.eia.gov/totalenergy/data/monthly/pdf/sec8_3.pdf; U.S. Energy Information Administration, "Vermont Yankee Nuclear Plant Closure in 2014 Will Challenge New England Energy Markets," September 6, 2013, accessible at http://www.eia.gov/todayinenergy/detail.cfm?id=12851.
42. H. Northey, "Nuclear: Spate of Reactor Closures Threatens U.S. Climate Goals—DOE," *Greenwire*, February 5, 2014, E&E Publishing, LLC, accessible at http://www.eenews.net/greenwire/stories/1059994082; P. Maloney, "Power Price Recovery May Be Too Late to Aid Its Nuclear Plants: Exelon Exec," Platts.com, April 9, 2014, McGraw Hill Financial, Las Vegas, accessible at http://www.platts.com/latest-news/electric-power/lasvegas/power-price-recovery-may-be-too-late-to-aid-its-21452315.
43. U.S. Environmental Protection Agency, "Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, Section X. Impacts of the Proposed Action," Proposed Rule, June 2014, accessible at http://www.gpo.gov/fdsys/pkg/FR-2014-06-18/pdf/2014-13726.pdf
44. See, for example, Sebastian Rausch and John Reilly, 2012, "Carbon Tax Revenue and the Budget Deficit: A Win-Win-Win Solution?" Report 228, August, MIT Joint Program on the Science and Policy of Global Change, accessible at http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt228.pdf; and Adele C. Morris, and Aparna Mathur, 2014, "A Carbon Tax in Broader U.S. Fiscal Reform: Design and Distributional Issues," Center for Climate and Energy Solutions, May, accessible at http://www.brookings.edu/~/media/research/files/papers/2014/05/22%20carbon%20tax%20broader%20us%20fiscal%20regulation%20morris/05222014_carbon_tax_broader_us_fiscal_reform_morrisa_mathura.pdf.
45. Ibid.
46. M. Bolinger, "An Analysis of the Costs, Benefits, and Implications of Different Approaches to Capturing the Value of Renewable Energy Tax Incentives," May 2014, accessible at http://eetd.lbl.gov/sites/all/files/lbnl-6610e_0.pdf.
47. H. C. Granade, J. Creyts, A. Derkach, P. Farese, S. Nyquist, and K. Ostrowski, 2009, "Unlocking Energy Efficiency in the U.S. Economy," July 2009, McKinsey Global Energy and Materials, accessible at http://www.greenbuildinglawblog.com/uploads/file/mckinseyUS_energy_efficiency_full_report.pdf; National Academy of Sciences, National Academy of Engineering, and National Research Council, 2010, "Real Prospects for Energy Efficiency in the United States," The National Academies Press, Washington, DC, accessible at http://www.nap.edu/openbook.php?record_id=12621.
48. A New Buildings Institute review of nine projects across the country showed that deep commercial retrofits are capable of reducing energy use by 30 percent or more, cutting energy costs in half, and elevating building performance to 50 percent better than the national average. See New Buildings Institute, 2011, "A Search for Deep Energy Savings," August, accessible at http://newbuildings.org/sites/default/files/NEEA_Meta_Report_Deep_Savings_NBI_Final8152011.pdf. Residential retrofits through DOE's Building America program—which aims to reduce energy use in new and existing homes 50 percent by 2017 through cost-effective measures—demonstrate that it is possible to bring existing building performance up to the same standard as best-in-class new construction. Homes in the program demonstrated average energy savings of nearly 60 percent, with some homes reaching as high as 90 percent improvement. See http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/der_pilot_mass_rhodeisland.pdf.
49. Unpublished data provided by Energy Efficiency Standards Group, Lawrence Berkeley National Laboratory. See Lawrence Berkeley National Laboratory, 2013, "Energy and Economic Impacts of U.S. Federal Energy and Water Conservation Standards Adopted from 1987 through 2012," accessible at http://eetd.lbl.gov/sites/all/files/standards_1987-2012_impacts_overview_lbnl-6217e.pdf.
50. For example, see U.S. Department of Energy, "Revolution Now: The Future Arrives for Four Clean Energy Technologies," accessible at http://energy.gov/sites/prod/files/2013/09/f2/Revolution%20Now%20--%20The%20Future%20Arrives%20for%20Four%20Clean%20Energy%20Technologies.pdf; and E. Perratore, "LG's New Dryer Saves Energy and Money: Uses a Hybrid Heat Pump to Recycle Wasted Heat," *Consumer Reports*, January 14, accessible at http://www.consumerreports.org/cro/news/2014/01/lg-s-new-dryer-saves-energy-and-money/index.htm.
51. Projections based on 100-percent state adoption of moderate and aggressive building codes, increased stringency of existing appliance standards, and adoption of appliance standards for new products. For more details, see Institute for Electric Innovation (IEE), an institute of the Edison Foundation, 2013, "Factors Affecting Electricity Consumption in the United States (2010-2035)," March, Edison Foundation, accessible at: http://www.edisonfoundation.net/iei/Documents/IEE_FactorsAffectingUSElecConsumption_Final.pdf.
52. There is no single definition of "energy efficiency resource standards." The 24 states include those that set mandatory, long-term targets for electricity, either as part of a specific standard (with sufficient funding to achieve these targets according to the American Council for an Energy-Efficient Economy), a combined renewable portfolio standard and efficiency standard, or an "all cost-effective" energy policy, and are sufficiently funded to meet these targets. For more details, see http://aceee.org/sites/default/files/publications/researchreports/u1403.pdf.
53. Savings estimate based on a review of 23 states programs for which cost and savings data were available for existing programs. These data were available in all but one state with energy efficiency resource standards (North Carolina). See Chapter 2 of the full working paper for details.
54. Estimate made using an updated version of the World Resources Institute's emission model described in "Can the U.S. Get There From Here?" For details about the model, see Bianco et al., 2013, "Can the U.S. Get There from Here?"
55. U.S. Department of Energy, U.S., Building Energy Codes Program, 2013, "National Benefits Assessment 1992–2040," accessible at http://assets.fiercemarkets.com/public/sites/energy/reports/usdebuildingcodereport.pdf.
56. U.S. Department of Energy (DOE), 2014, Building Energy Codes Program: "Status of State Energy Code Adoption," July, U.S. DOE Office of Energy Efficiency & Renewable Energy, accessible at http://www.energycodes.gov/adoption/states.

57. U.S. Department of Energy, 2012, "DOE and Private-Sector Partners Introduce a New Money-Saving Specification for Commercial Air Conditioners," April, DOE Office of Energy Efficiency & Renewable Energy, Building Technologies Program, accessible at http://apps1.eere.energy.gov/buildings/publications/pdfs/alliances/techspec_rtus.pdf.
58. Advanced RTU (Rooftop Unit) Campaign, "Awards & Results," accessed September 2, 2014, accessible at http://www.advancedrtu.org/awards--results.html.
59. U.S. Department of Energy, "Install Units Produced by the High Performance Rooftop Unit Challenge that Meet the High Performance Rooftop Unit Specification," 2011, accessible at http://www4.eere.energy.gov/alliance/activities/technology-solutions-teams/space-conditioning/rtu.
60. Intelligent Building Energy Information and Control Systems for Low-Energy Operations and Optimal Demand Response, 2012, Lawrence Berkeley National Laboratories, http://eetd.lbl.gov/sites/all/files/LBNL-5894E.pdf
61. U.S. Department of Energy (DOE), Office of Energy Efficiency & Renewable Energy, 2013, Advanced Manufacturing Office, "Wide Bandgap Semiconductors: Pursuing the Promise," April, DOE/EE-0910, accessible at http://www1.eere.energy.gov/manufacturing/rd/pdfs/wide_bandgap_semiconductors_factsheet.pdf.
62. Light-duty cars and trucks with a gross vehicle weight rating of 8,500 pounds or less.
63. The Department of Energy has a target of reducing the cost for long-range electric vehicle batteries from $500 per kilowatt hour in 2012 to $125 per kilowatt hour by 2022 (U.S. Department of Energy, 2013,"EV Everywhere Grand Challenge Blueprint," accessible at: http://energy.gov/sites/prod/files/2014/02/f8/eveverywhere_blueprint.pdf). At this price point, along with other concomitant advancements, DOE expects long-range (280 miles) electric vehicles to be cost-competitive with internal combustion engines (on a levelized total cost of ownership basis over five years). DOE notes that shorter-range electric vehicles and plug-in hybrids would likely become cost-competitive before this price point for long-range electric vehicle batteries is met. Tesla Motors recently announced plans to build facilities by 2017 to produce large electric vehicle batteries that are 30 percent cheaper than today's batteries (around $190 per kilowatt hour, assuming current reported prices, see Chapter 3 for additional discussion).
64. The standards require a continuous improvement in vehicle performance, so that on average model year 2025 vehicles emit 163 grams of carbon dioxide equivalent per mile (CO_2e per mile), which is equivalent to 54.5 miles per gallon if the improvements are achieved exclusively through fuel economy improvements. This results in an equivalent fuel-economy standard of 49.7 miles per gallon because DOT considers only drivetrain improvements and does not consider improvements in air conditioning leakage of HFCs.
65. These ranges are based on lifetime net present value with 7 and 3 percent discount rates, respectively, using 2010 dollars. While more efficient vehicles are expected to cost more than their counterparts, EPA estimates that fuel savings from model year 2025 vehicles will offset the higher vehicle cost in less than 3.5 years if those vehicles are purchased outright by the consumer. However, consumers that purchase their new model year 2025 vehicle with a standard five-year loan will benefit right away because fuel savings will offset loan repayments by $12 each month. See U.S. Environmental Protection Agency, Office of Transportation and Air Quality, 2012, "EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years 2017–2025 Cars and Light Trucks," Regulatory Announcement, EPA-420-F-12-051, August 2012, accessible at: http://www.epa.gov/otaq/climate/documents/420f12051.pdf.
66. A.P. Bandivadekar and J.B. Heywood, 2004, "Coordinated Policy Measures for Reducing the Fuel Consumption of the U.S. Light-Duty Vehicle Fleet," LFEE 2004-001 RP, Laboratory for Energy and the Environment, Massachusetts Institute of Technology, Cambridge, MA, accessible at http://web.mit.edu/sloan-auto-lab/research/beforeh2/files/bandivadekar_policy.pdf; E.W. Chow, 2013, "Exploring the Use of a Higher Octane Gasoline for the U.S. Light-Duty Vehicle Fleet," Thesis, May 10, Massachusetts Institute of Technology, accessible at: http://web.mit.edu/sloan-auto-lab/research/beforeh2/files/Eric_Chow_Thesis.pdf.
67. E.W. Chow, 2013. "Exploring the Use of a Higher Octane Gasoline for the U.S. Light-Duty Vehicle Fleet."
68. U.S. Environmental Protection Agency, 2013, "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2013," December, accessible at http://www.epa.gov/fueleconomy/fetrends/1975-2013/420r13011.pdf.
69. Argonne National Laboratory, Transportation Technology R&D Center, 2014, "Light Duty Electric Drive Vehicles Monthly Sales Updates," Technology Analysis, U.S. Department of Energy, accessible at http://www.transportation.anl.gov/technology_analysis/edrive_vehicle_monthly_sales.html. As noted in EPA's Regulatory Impact Analysis, EPA expects electric vehicles to make up 2 percent of the new light-duty fleet in 2025, on average. This equates to just over 316,000 electric vehicles, if 2025 sales are consistent with EIA's *Annual Energy Outlook 2014* Reference Case projections (1.58 million light duty vehicle sales in 2025).
70. See U.S. Environmental Protection Agency, 2012, Regulatory Impact Analysis: "Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards," Table 3.5–25 Final Rule Fleet Technology Penetration in MY 2025, August, accessible at http://www.epa.gov/otaq/climate/documents/420r12016.pdf; and U.S. Energy Information Administration, "Light Duty Vehicle Sales by Technology Type," in *Annual Energy Outlook 2014*, accessible at http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2014&subject=15-AEO2014&table=48-AEO2014&region=1-0&cases=ref2014-d102413a.
71. For more information, see ZEV Program Implementation Task Force, 2014, "Multi-State ZEV Action Plan," May, Office of Governor Martin O'Malley, Annapolis, MD, accessible at http://governor.maryland.gov/documents/MultiStateZEVActionPlan.pdf.
72. U. Irfan, 2014, "AUTOS: Tesla Lays Out Details for Massive Proposed Battery Factory," February 27, 2014. *ClimateWire*, Environment & Energy, LLC., accessible at http://www.eenews.net/climatewire/stories/1059995230/print.
73. Bloomberg New Energy Finance, 2014, *Sustainable Energy in America 2014* Factbook, February, The Business Council for Sustainable Energy, accessible at http://www.bcse.org/factbook/pdfs/2014%20Sustainable%20Energy%20in%20America%20Factbook.pdf.
74. Ibid.
75. U.S. Department of Energy, "Accomplishments and Progress," in About the Fuel Cell Technologies Office, DOE Office of Energy Efficiency & Renewable Energy, accessed September 2, 2014, accessible at http://energy.gov/eere/fuelcells/accomplishments-and-progress.
76. Jacob S. Spendelow, Fuel Cell Technologies, U.S. Department of Energy, personal communication, April 17, 2014.

77. The Nissan Leaf has a range of 84 miles, the Tesla Model S has a range of 208–265 miles depending on the size of the battery while the Chevy Volt has an electric-only range of 38 miles. Nissan Motor Co., 2014, “2014 Nissan Leaf Charging & Range,” accessible at http://www.nissanusa.com/electric-cars/leaf/charging-range/; Tesla Motors, Inc. 2014, “Model S Design Studio,” accessible at http://www.teslamotors.com/models/design; Chevrolet, 2014, “Chevy Volt Electric Car,” accessible at http://www.chevrolet.com/volt-electric-car/faq.html.
78. K. Bullis, “Electric Vehicles Out in the Cold,” *MIT Technology Review*, December 13, 2013, accessible at http://www.technologyreview.com/news/522496/electric-vehicles-out-in-the-cold/.
79. U.S. Department of Energy, Alternative Fuels Data Center: Alternative Fueling Station Locator, DOE Office of Energy Efficiency & Renewable Energy, June 2014, accessible at http://www.afdc.energy.gov/locator/stations/results?utf8= percentE2percent9Cpercent93&location=&filtered=true&fuel=ELEC&owner=all&payment=all&ev_level1=true&ev_level2=true&ev_dc_fast=true&radius_miles=5.
80. U.S. Energy Information Administration, “Access to Alternative Transportation Fuel Stations Varies across the Lower 48 States,” *Today in Energy*, April 30, 2012, accessible at http://www.eia.gov/todayinenergy/detail.cfm?id=6050#tabs_AltTransportFuelStations-3.
81. U.S. Department of Transportation, Alternative Fuels Data Center: Alternative Fueling Station Locator, June 2014, accessible at: http://www.afdc.energy.gov/locator/stations/.
82. California Environmental Protection Agency Air Resources Board, 2014, “Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development,” June, accessible at http://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_final_june2014.pdf.
83. Note, this analysis defines net present value (NPV) as “the sum of all costs and benefits from 2010 to 2050, plus the fuel, greenhouse gases, and petroleum costs and benefits of vehicles sold through 2050 that will still be in use beyond that date.” A 2.3 percent rate for all years was used, which is consistent with the most recent guidance of the U.S. government. See “Table 5.3 Summary of Estimated Petroleum and GHG Reductions in the Policy Cases,” and “Table 5.4 Total Net Present Value in 2050 for Various Cases for the NPV across All Policy Cases Modeled in: National Research Council, 2013,” in *Transitions to Alternative Vehicles and Fuels*, National Academies Press, Washington, DC, accessible at http://www.nap.edu/catalog.php?record_id=18264.
84. According to the latest estimates from the Intergovernmental Panel on Climate Change, because it is a powerful but short-lived greenhouse gas, methane traps 34 times as much heat in the atmosphere as CO_2 over 100 years, and 86 times as much over 20 years. See G. Myhre and D.Shindell, “Anthropogenic and Natural Radiative Forcing,” in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, UK: Cambridge University Press, accessible at http://www.climatechange2013.org/images/report/WG1AR5_Chapter08_FINAL.pdf.
85. ICF International, 2014, “Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries,” March, Fairfax, VA, accessible at http://www.edf.org/sites/default/files/methane_cost_curve_report.pdf.
86. Methane is the primary component of natural gas, but gas also has significant concentrations of volatile organic compounds–many of which are precursors to ground-level ozone formation. Hazardous air pollutants are present in unprocessed natural gas. For more information, see R. Lattanzio, “Air Quality Issues in Natural Gas Systems,” Congressional Research Service, March 2013, accessible at http://www.civil.northwestern.edu/docs/Tight-Shale-Gas-2013/Air-Quality-Issues-Natural-Gas-Ratner-2013.pdf.
87. U.S. Environmental Protection Agency, 2014, “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012. Chapter 3: Energy,” April, EPA, Washington DC, accessible at http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.
88. S. Harvey, V. Gowrishankar, and T. Singer, 2012, “Leaking Profits: The U.S. Oil and Gas Industry Can Reduce Pollution, Conserve Resources, and Make Money by Preventing Methane Waste,” March, Natural Resources Defense Council, New York, NY, accessible at http://www.nrdc.org/energy/leaking-profits.asp; and ICF International, 2014, “Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries,” March, Fairfax, VA, accessible at http://www.edf.org/sites/default/files/methane_cost_curve_report.pdf.
89. U.S. Environmental Protection Agency, “Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews,” accessible at http://www.epa.gov/airquality/oilandgas/pdfs/20120417finalrule.pdf.
90. N. Fann, C.M. Fulcher, and B.J. Hubbell, “The Influence of Location, Source, and Emission Type in Estimates of Human Health Benefits of Reducing a Ton of Air Pollution,” *Air Quality, Atmosphere, & Health*, September 2009: 169–76, accessible at http://www.ncbi.nlm.nih.gov/pubmed/19890404.
91. U.S. Energy Information Administration, 2014, “Natural Gas Spot and Futures Prices (NYMEX),” in Natural Gas, accessible at http://www.eia.gov/dnav/ng/ng_pri_fut_s1_a.htm.
92. See U.S. Energy Information Administration, “Henry Hub Natural Gas Spot Price,” accessed September 6, 2014, accessible at http://www.eia.gov/dnav/ng/hist/rngwhhdm.htm.
93. For price projections from the International Monetary Fund, World Bank, and Economist Intelligence Unit, see I. Kolesnikov, “Natural Gas Prices: Long Term Forecast to 2020, Data and Charts, 2011–2014,” Knoema, accessible at: http://knoema.com/ncszerf/natural-gas-prices-long-term-forecast-to-2020-data-and-charts.
94. HCFCs have been used as a replacement for CFCs, another group of ozone-depleting substances with high global warming potentials, which have been phased out under the Montreal Protocol (except for allowed exemptions). See U.S. Environmental Protection Agency, “The Phaseout of Ozone-Depleting Substances,” March 2014, accessible at http://www.epa.gov/ozone/title6/phaseout/. Because of the success of this phase-out, the Montreal Protocol has already spurred large greenhouse gas benefits. However, this trend is starting to reverse because of the rise of HFCs.
95. European Fluorocarbons Technical Committee, “Hydrofluoroolefins (HFOs) Factsheet,” June 2011, accessible at: http://www.fluorocarbons.org/uploads/Modules/Library/fact-sheet-hfos_19.pdf.
96. The United Nations Environment Programme defines transcritical CO_2 systems as: “Refrigeration systems that use CO_2 as a primary refrigerant...In transcritical CO_2 refrigeration systems, CO_2 is the sole refrigerant, evaporating in the subcritical region and rejecting heat at temperatures above the critical point in a gas cooler instead of a condenser” See: United Nations Environment Programme and Climate and Clean Air Coalition, 2014, “Low-GWP Alternatives in Commercial

Refrigeration: Propane, CO_2 and HFO Case Studies," accessible at http://www.unep.org/ccac/portals/50162/docs/Low-GWP_Alternatives_in_Commercial_Refrigeration-Case_Studies-Final.pdf.

97. R744.com, "CO_2 Transcritical Milestones—3-Year Payback and Now in the US—Latest from ATMOsphere America," June 27, 2013, accessible at http://www.r744.com/news/view/4345.
98. Coca-Cola Company, 2014, "Coca-Cola Installs 1 Millionth HFC-Free Cooler Globally, Preventing 5.25MM Metric Tons of CO_2," Press Release, January 22, accessible at http://www.coca-colacompany.com/press-center/press-releases/coca-cola-installs-1-millionth-hfc-free-cooler-globally-preventing-525mm-metrics-tons-of-co2#TCCC.
99. Ibid.
100. PepsiCo, "PepsiCo Debuts Energy-Efficient, HFC-Free Cooler at Super Bowl," Press Release, February 2010, accessible at http://www.pepsico.com/Media/PressRelease/PepsiCo-Debuts-Energy-Efficient-HFC-Free-Cooler-at-Super-Bowl02022010.html; Red Bull, "Efficient Cooling through Ecofriendly Coolers," accessible at http://energydrink.redbull.com/coolers; Heineken, "2013 Sustainability Report," accessible at http://sustainabilityreport.heineken.com/The-big-picture/What-we-said-and-what-weve-done/index.htm; Hydrocarbons 21, "Heineken's Successful Rollout of HC Coolers—Exclusive Interview with Maarten ten Houten," December 2013, accessible at http://www.hydrocarbons21.com/news/viewprintable/4760; Ben & Jerry's, "Experience with Natural Refrigerants," accessible at http://www.atmo.org/presentations/files/124_3_Asch_Ben_n_Jerry.pdf.
101. Ford Motor Company, 2012, "Beyond CO_2," accessible at http://corporate.ford.com/microsites/sustainability-report-2011-12/environment-climate-issue-beyond; G. Nelson, Automotive News, December 2013, "Automakers' Switch to New Refrigerant Will Accelerate with EPA Credits, European Mandate," accessible at: http://www.autonews.com/article/20131230/OEM01/312309996/automakers-switch-to-new-refrigerant-will-accelerate-with-epa-credits-; General Motors, July 2010, "GM First to Market Greenhouse Gas-Friendly Air Conditioning Refrigerant in U.S.," accessible at: http://media.gm.com/content/Pages/news/us/en/2010/July/0723_refrigerant/_jcr_content/iconrow/wordfile/file.res/072310%20New%20Refrigerant%20%20FINAL.doc.
102. HFO-1234yf has a GWP of 4 whereas the current refrigerant, HFC-134a, has a GWP of 1,430. See U.S. Environmental Protection Agency, "Final Rulemaking Protection of the Stratospheric Ozone: New Substitute in the Motor Vehicle Air Conditioning Sector under the Significant New Alternatives Policy (SNAP) Program," Fact Sheet, accessible at http://www.epa.gov/ozone/downloads/HFO-1234yf_Final_Fact_Sheet.pdf.
103. Simon Warburton, "Honeywell Fights Back Against r1234yf Claims," Just Auto, May 2014, accessible at http://www.just-auto.com/news/honeywell-fights-back-against-r1234yf-claims_id145919.aspx.
104. DuPont, "Rapid Growth Expected in Adoption of HFO-1234yf," accessible at http://us.vocuspr.com/Newsroom/MultiQuery.aspx?SiteName=DupontEMEA&Entity=PRAsset&SF_PRAsset_PRAssetID_EQ=128793&XSL=NewsRelease&IncludeChildren=True&Lang=English.
105. Consumer Goods Forum, November 2010, "Consumer Goods Industry Announces Initiatives on Climate Protection," accessible at http://www.theconsumergoodsforum.com/consumer-goods-industry-announces-initiatives-on-climate-protection.
106. U.S. Environmental Protection Agency, 2014, "Global Mitigation of Non-CO_2 Greenhouse Gases: 2010–2030," Executive Summary, April, EPA Office of Atmospheric Programs, Washington, DC, accessible at http://www.epa.gov/climatechange/EPAactivities/economics/nonco2mitigation.html.
107. U.S. Environmental Protection Agency, 2013, "Benefits of Addressing HFCs under the Montreal Protocol," June, EPA Stratospheric Protection Division, Office of Atmospheric Programs, Office of Air and Radiation, Washington, DC, accessible at http://www.epa.gov/ozone/downloads/Benefits_of_Addressing_HFCs_Under_the_Montreal_Protocol_6-21-2013.pdf.
108. *Wall Street Journal*, "Honeywell Announces Major Investments to Increase HFO-1234yf Production in the United States," December 10, 2013, accessible at http://online.wsj.com/article/PR-CO-20131210-905083.html?dsk=y.
109. Arkema, "Arkema Is Announcing the Construction of Production Capacities for New Refrigerant Fluorinated Gas 1234yf,"Press Release, September 2013, accessible at http://www.arkema.com/en/media/news/news-details/Arkema-is-announcing-the-construction-of-production-capacities-for-new-refrigerant-fluorinated-gas-1234yf/?back=true.
110. DuPont, "DuPont Fluorochemicals Announces Production Plans to Support the Introduction of a New Formacel® Foam Expansion Agent with Low Global Warming Potential," Press Release, April 10, 2014. DuPont Fluorochemicals, accessible at http://www2.dupont.com/Formacel/en_US/assets/downloads/20140410_article.pdf.
111. Hydrocarbons21.com, 2013, "ATMOsphere Europe 2013: Buoyant Market for Hydrocarbons in Light Commercial Refrigeration," Shecco, October 24, 2013, accessible at http://www.hydrocarbons21.com/news/viewprintable/4648; Hydrocarbons21.com, 2013, "Heineken's Successful Rollout of HC Coolers—Exclusive Interview with Maarten Houten," Shecco, December 4, 2013, accessible at http://www.hydrocarbons21.com/news/viewprintable/4760.
112. Michael Parr, federal government affairs manager, DuPont, personal communication, July 24, 2014.
113. U.S. Environmental Protection Agency, 2014, "Text of North American HFC Phase-Down Amendment Proposal," accessible at: http://www.epa.gov/ozone/downloads/HFC_Amendment_2014_Text.pdf.
114. U.S. Environmental Protection Agency, "Recent International Developments under the Montreal Protocol," in Ozone Layer Protection, last updated on July 11, 2014, accessible at http://www.epa.gov/ozone/intpol/mpagreement.html.
115. The Alliance for Responsible Atmospheric Policy, "Responsible Policy for a Responsive Industry," accessed September 2, 2014, accessible at http://www.arap.org/downloads/alliance-overview.pdf.
116. The Alliance for Responsible Atmospheric Policy recently petitioned EPA to extend the rules on air conditioning and refrigerant management in section 608 of the Clean Air Act to HFCs (See Alliance for Responsible Atmospheric Policy, "Petition to Extend the Requirements of 40 C.F.R. Part 82, Subpart F to HFCs," January 2014, accessible at http://www2.epa.gov/sites/production/files/2014-05/documents/alliance-petition-31jan2014-v2-2.pdf). This action is also included in the proposed senate bill, the Super Pollutants Act of 2014 (See "Super Pollutants Act of 2014," accessible at http://www.murphy.senate.gov/download/super-pollutants-act_-bill-text?id=be4ed0be-4cef-49d9-aaa2-338cdebfceba&download=1).